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The

Papua and New Guinea

Agricultural Journal

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CONTENTS

	Page
Shifting Cultivation and Crop Rotations in the Tropics—K. Newton	93
The Root-Knot Nematode—L. B. Thrower	131
Suspected Botulism in Poultry—T. L. W. Rothwell	137

Former Issues of *Gazette* and *Journal*

The following numbers of the *Agricultural Gazette* have been issued :

New Guinea Agricultural Gazette—

Volume 1, Number 1.
Volume 2, Numbers 1, 2 and 3.
Volume 3, Numbers 1 and 2.
Volume 4, Numbers 1, 2, 3 and 4.
Volume 5, Numbers 1, 2 and 3.
Volume 6, Numbers 1, 2 and 3.
Volume 7, Numbers 1, 2, 3 and 4.

The Papua and New Guinea Agricultural Gazette—

Volume 8, Numbers 1, 2, 3 and 4.

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Volume 9, Numbers 1, 2, 3 and 4.
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Copies of all numbers of the *Gazette* to Volume 7, No. 4, are out of print.

CORRIGENDUM

The editorial committee wishes to express its sincere regrets for the errors occurring in figures III and IV of the article titled "Stimulation of the Yield of Rubber Trees as a Routine Estate Practice" printed in Volume 13, No. 1 of this Journal. The article was reprinted from Planters Bulletin No. 45 by courtesy of the Rubber Research Institute of Malaya.

The corrected figures are inserted in this issue of the Journal and the following substitutions should be made in Volume 13, No. 1 : Fig. III in the current issue for Fig. III, page 18, and Fig. IV, page 20.

SHIFTING CULTIVATION AND CROP ROTATIONS IN THE TROPICS

BY K. NEWTON *

INTRODUCTION

THE pressing need for the development or improvement of peasant farming systems in tropical and sub-tropical areas under conditions of increasing human and stock populations is a problem with which most agriculturalists are well acquainted and on which a vast amount of research has been carried out in many different climates on varying soil types.

Insofar as pure subsistence agriculture is concerned, accumulated results have indicated the value and place of farmyard manure, composts, fertilizers, grass leys and green manures in the system. This paper is mainly concerned with an assessment of the results from crop rotation trials in which legumes used either as cover crops or green manures have been tested for their capacity to maintain the fertility of the soil as measured by crop yields.

The problem of shifting cultivation or bush fallow rotation with its various advantages and disadvantages is outlined, some theoretical aspects of the functions of leguminous cover crops or green manures are discussed, and experimental evidence in the literature of the value of legumes in crop rotations surveyed.

At the end of the article a list of the main publications which have been checked is provided for the benefit of persons interested in further investigation into this aspect of peasant farming.

SECTION 1

An Outline of Shifting Cultivation (Bush fallow rotation)

In many tropical areas of the world the traditional subsistence agriculture is based on shifting cultivation or bush fallow rotation. These two terms are used synonymously in many cases in the literature, but, if differentiation is necessary, the general practice under shifting cultivation is that land is cleared and cropped for two to three years after which it is abandoned while the cultivator shifts to a new area. Cessation of the use of a cultivated garden area may be due to one or several factors. In some cases depletion and erosion lead to such a decline in yields that cropping is no longer worthwhile, but in many instances land is abandoned not because of lower productivity but because less labour is involved in clearing new land than in weeding old gardens where weed species are established. The system is used in some areas where the indigenous inhabitants own very large areas of land over which gardens can be moved at will. Under a bush fallow rotation the land is cleared and cropped for two to three years, allowed to revert to a natural vegetation cover and then after a time interval of anything from three to fifteen years the cultivator returns to the area and crops it again. The bush fallow rotation with gardens being shifted over a definite and limited area is perhaps the more general pattern of subsistence agriculture in use, the length of the fallow being dependent on several factors, the most important of which is probably population pressure. As population increases on a limited area of land so the length of the fallow period is reduced to enable a greater production of food.

The preparation of a garden area for cultivation follows a general pattern whereby the light bush and undergrowth is cleared at ground level, the heavier trees chopped down about three feet above ground level, and the whole area, in most cases, burnt. It is worthy of note that experimental work in the Chad Territory of French Equatorial Africa (Johnston, 1958) calls attention to a relatively simple modification of this traditional practice which holds considerable promise. Tests showed that stump regeneration is improved considerably when, at the time of clearing, trees and bushes are cut off level with the ground instead of a yard above and if the cuttings are heaped up

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for burning between the roots instead of on top. This fact, however, is apparently well known to the Ibos and people of some other areas in both Eastern and Western Nigeria. The first crops planted on the cleared area are usually annual foodcrops—sweet potatoes, colocasia, maize, millet, yams and so on, and these are followed by perennial crops such as cassava and bananas. The later crops are weeded perhaps once or twice and then harvested. After two to three years they are overgrown by the regenerating natural vegetation.

An attempt to evaluate the practice of burning felled bush before planting has been made in Sierra Leone where the characteristic form of subsistence farming in the upland region is that of a bush fallow rotation, a system which has been described as both "pernicious and causing the degradation of the soil in the upland region of the country" and "a concession to the character of the soil which needs long periods for recovery and regeneration" (Dougall, 1948). A field study was made at Njala Experiment Station to obtain information on the merits or demerits of burning cleared bush prior to cropping the land with upland rice. Rainfall at the station is approximately 110 in. per annum with one wet season from May to November. The station is approximately 400ft. above sea level and located on deep, acid (pH 5.2), reddish brown gravel loam derived from sedimentary rocks carrying a vegetation cover of secondary bush less than seven years old on the site of the experiment.

Three different clearing treatments were applied, each on a one-acre block with no replications :

(1) Brushing and burning secondary bush *in situ* and incorporating the ash ;

(2) Brushing, burning the bush elsewhere, returning the ash to the block and incorporating in the soil ; and

(3) Brushing and complete removal of the vegetation.

Yields.—(1) 886 lb. padi/acre

Yields.—(2) 327 lb. padi/acre

Yields.—(3) 199 lb. padi/acre

PLATE 1.—*An early stage of bush fallow on a peasant farm near Ibadan in Nigeria.*

The results indicate that treatment 1 was superior to the other two treatments but unfortunately the most valuable comparative treatment which could have been included, that is brushing and leaving the bush to decompose, was omitted.

References to the use of bush fallow rotations are to be found in the literature from a large number of tropical areas. In Nigeria (Nye and Hutton, 1957) the traditional method for restoring the fertility of poor, red sandy soils in the forest region around Benin after cropping for about two years is to use a bush fallow rotation for some six to eight years. Cassava, which is usually the last crop, forms part of the fallow for the first few years until forest shrubs and trees become dominant. Generally throughout Southern Nigeria a bush fallow rotation is practised, the cropping cycle lasting for up to three years and the bush fallow for three to seven years (Lewin, 1931).

In the Belgian Congo, the traditional agriculture throughout the country is also one of bush fallow rotation, cultivation alternating with very long fallow periods and frequent shifts to new land being common (Tondeur, 1955). The cropping practices most frequently employed in the Central Congo Basin permit the return of forest species within two to three years after the forest is cut, initiating a forest fallow or regeneration period which may vary from about 15 years under Government supervision to erratic, indefinite fallow periods where operated entirely by native farmers.

Similar rotations have been described for many other areas in Africa, the crops used varying with climate, soils and tradition and the length of both the cropping cycle and bush or grass fallow varying with soil fertility and population pressure.

In the Melanesian islands of the Pacific a definite range of subsistence economies and agricultural systems have been evolved, all of which are based on the bush fallow rotation. Table 1. (Barrau, 1958). It has been found that even though the systems are varied they are all so closely dependent on environment that almost identical agricultural patterns, corresponding to a particular ecological environment, are in use in areas as far apart as New Caledonia and New Guinea. The original form of Melanesian agriculture was one of shifting cultivation and the present form is one of bush fallow rotation, but there are few areas which have been settled by Europeans for over a century where agriculture with rotations and fertilizers is practised.

The value of a bush or forest fallow as a means of restoring soil fertility has long been recognized, initially of course by the subsistence farmers themselves and latterly by scientists and research workers, but surprisingly little work has been done on the assessment of the rate and magnitude of nutrient immobilization by a regenerating bush fallow and the rate of decomposition and mineralization of plant material on the forest floor. Perhaps the only thorough investigation of these processes has been carried out by research workers in the Belgian Congo who have shown (Bartholemew *et al,* 1953) that nutrient immobilization in the forest fallow is rapid at the onset and in five years of forest fallow (tropical rainforest) the quantity of total nutrients immobilized is more than half as great as in eighteen years. Little difference was found in total immobilization of nutrients between five and eight year old fallow. Further, it was found that leaf growth rapidly approaches a maximum and later increases in total growth occur chiefly in the woody parts, particularly the above ground parts. Roots also rapidly approach a maximum with 75 per cent. as much growth at five years as at eighteen years. Litter accumulation builds up from leaf and stem residues and closely approaches a maximum between eight and twelve years. Although leaves comprise a small proportion of the total weight of plant parts, except in the early stages of establishment of the forest fallow, and living woody tissue, both above ground and roots, account for most of the total weight, nutrient immobilization is considerably more important in leaves, particularly the uptake and release of nitrogen.

The same Belgian workers compared the quantities of nutrients immobilized in fallow vegetation with the quantities in a fairly poor soil and found that the total supply of nitrogen and phosphorus in the soil, which must make some contribution to plant growth, is very large in comparison with that immobilized in fallow vegetation. Nitrogen in the soil is largely tied up in organic combinations and becomes available only through biological decomposition of soil organic matter. It may also be added to the soil through biological fixation from atmos-

TABLE I

—	Lowlands		Foothills and Counterparts.	Highlands.	Coastal Mountain Chains.	
Predominant form of vegetation	Mangrove and swampy forest featuring *Metroxylon rumphii*	Savannah woodland and grassland and occasionally strand vegetation	Savannah, grassland and rain forest	Grassland and swampy grassland, rain forest and moss forest	Mangrove and swampy forest featuring *Metroxylon rumphii*	Rain forest and strand vegetation
Traditional subsistence economy	Foraging—fishing and/or hunting—gardening with bush fallow rotation	Gardening with bush fallow rotation + foraging + fishing and/or hunting	Gardening with bush fallow rotation + foraging + fishing and/or hunting	(*a*) Semi-sedentary agriculture with fallow, compost and drainage (*b*) Gardening with bush fallow rotation + foraging + fishing and/or hunting	Foraging + gardening with bush fallow rotation + fishing and/or hunting	Gardening with bush fallow rotation + foraging + fishing and/or hunting
Main vegetable foods in order of importance	Sago	Tubers Sago Bananas *Saccharum* spp.	(*a*) Tubers Bananas *Saccharum* spp. (*b*) Bananas Tubers *Saccharum* spp.	Tubers Greens	Sago Tubers Bananas *Saccharum* spp.	Tubers Sago Bananas *Saccharum* spp.
Estimate of garden area Acres/capita	Less than 0.1	0.1-0.2	0.12-0.25	(*a*) 0.1-0.2 (*b*) 0.15-0.3	Less than 0.12	0.15-0.3

pheric sources. Some phosphorus is associated with the nitrogen in organic matter and is mineralized along with nitrogen and thus becomes available to crops. The exchangeable cations were found to be somewhat comparable in quantity to the amounts immobilized in fallow vegetation.

Finally, in a study of the decomposition and mineralization of plant material on the forest floor, it was found that decomposition processes on the forest floor of equatorial rain forest proceed rather rapidly, leaf residues failing to accumulate to the extent that they do in temperate zone forests. Rapid decomposition results from the fact that moisture conditions are usually optimum, temperature and humidity are usually high, and insect life is numerous. Some evidence was obtained that the rate of loss of the main nutrients during decomposition was uneven, the order being

N
S and P
K increasing rate of loss
Ca and Mg

However, there appears to be no proof at all as yet that nitrogen tie-up by micro-organisms occurs to any important extent in tropical forest conditions while results from Ghana (Greenland, 1959) indicate that 20 tons of straw with a carbon-nitrogen ratio of approximately 100 decomposes without causing a nitrogen negative period.

Advantages of the Bush Fallow rotation

There is little doubt that for subsistence agriculture the widely-practised system of bush fallow rotation which has been outlined above is a satisfactory method of maintaining soil fertility at a reasonable level, provided land availability does not limit the duration of the fallow period to the extent that it cannot build up fertility to a satisfactory level before another cropping cycle. Nye (1957) points out that the system has obvious merits in forest regions where broad-leaved fallows spring up spontaneously and rapidly from stumps with an already established root system left in the ground, and Vine (1959) has drawn attention to the fact that in some cases the tree species are especially selected for this purpose, e.g. *Acioa barteri, Macrolobium, Baphia* and other species in Eastern Nigeria. The break in the cropping controls weeds and plant pests and diseases which are liable to multiply under continuous cropping, as has been found in New Britain. There, the concentration of foodcrops into an area cleared from rain forest has resulted in a fairly rapid multiplication of diseases and pests of colocasia, sweet potato, peanuts and sorghum (unpublished work). The bush fallow generally requires no planting or physical management and the litter of the broad leaves decomposes to a type of humus which provides subsequent crops with abundant nitrate. Nowhere in fact does land rested for a reasonable time under broad-leaved fallow show immediate responses to applications of fertilizer, except possibly in areas of very high rainfall and very porous soils or where mineralization and nitrification may be inhibited by a very low pH.

In general, even though the system is expensive in terms of both land and labour, the bush fallow fulfils the main requirements for this method of agriculture. It accumulates plant nutrients in organic combination, thereby preventing nutrient loss, by virtue of plant immobilization, and improves soil structure by virtue of both rest from cultivation and biological activity. Elsewhere (Maher, 1949) the advantages of the bush fallow have been listed to include the addition of humus to the soil through leaf mould and the decay of twigs and roots, the prevention of erosion to some extent during the fallow period, the provision of shade and physical protection to the soil from rain, thereby reducing the rate of distintegration of both organic and inorganic crumbs, and the return of nutrients from lower levels in the soil profile to the surface through the action of deep rooted bush trees.

However it would be a fallacy to believe that the fallow creates plant nutrients or markedly accelerates their liberation from primary sources in the soil as it merely serves to conserve them so that a crop can be well nourished by the plant food biologically and chemically liberated at the conclusion of the fallow period. It is this transitional stage in the rotation between forest and cropping which is the most critical interval, particularly if the felled bush is burnt prior to cultivation. As previously pointed out, tropical vegetation does not have ground litter present to the same extent as forest in temperate regions because of the rapid destruction of plant residues through intense microbial activity consequent on high temperatures and humidity.

There is little accumulation of humus and fairly rapid infiltration of nutrients. Organic matter content of the soil under African equatorial forest may be as low as 1.8 per cent. (Tondeur, 1955) although Greenland (1959) has noted that it is seldom less than 4 per cent. in the 0-4 in. layer under forest of 20 years and over. However, a considerable quantity of organic matter is added to the soil in a short time when an area is cleared for cultivation and from this are liberated large quantities of mineral nutrients as a result of microbial decomposition or burning. Burning, which is probably the most common practice, besides rapidly liberating minerals from the trash, results also in the accelerated loss of N from the trash. This means therefore that there is a possibility of substantial plant nutrient loss before the cultivated crop is sufficiently developed to re-immobilize most of the nutrients. Possible loss may be reduced if the first crop is planted and grown concurrently with the decomposition and disintegration of trash. As rainfall, humidity and solar radiation increases in intensity on denuded soil, so the rate of loss of minerals, through leaching, run-off and percolation will increase on burnt areas. On unburnt areas, destruction of plant residues and colloidal humus of the soil by oxidation and microbial activity increases.

Consequently, a short cultivation period has to be followed by a long bush fallow, the purpose of which is to restore the organic humus reserve and the mineral fertility linked to this reserve by drawing on the deeper layers, and to restore the microbial balance in harmony with the climax vegetation. It is interesting to note however that work by Nye and Bertheaux on phosphate (Vine, 1959) tends to show that this action is less significant, for phosphate, than the conversion of topsoil phosphate to a condition of increased availability. Nevertheless, as long as rapid loss of fertility can be counteracted *only* by bush fallow, the system will remain an inescapable prerequisite for the production of annual foodcrops, although, as indicated earlier, data from fertilizer trials now show frequent responses to fertilizers, the magnitude of the response increasing as cultivation continues.

If the land is cropped for too long a period under systems of subsistence agriculture, productivity markedly declines and the natural vegetation species cannot be readily re-established. The fundamental causes for the decline in productivity have not yet been established (Bartholemew *et al*, 1953), but depletion of available nutrients and deterioration in tilth may well be amongst the most important. This point of view is not entirely supported by workers in Ceylon (Joachim and Kandian, 1948). There, soil analyses were carried out for the comparison of two identically-treated virgin jungle sites, cultivated on the bush fallow rotation system (jungle cut, burnt, two crops taken and land rested for five years), with other sites which included abandoned areas of bush fallow rotation, three to four years old jungle fallow, five to six-year-old jungle fallow, ten to twelve-year-old jungle fallow, high jungle, areas under cultivation and jungle sites before and after burning. The results indicated that while there were some losses of organic matter and N and mineral nutrients as a result of the use of bush fallow rotation, these would occur under any system of rotational cropping on new jungle land and are not such as would render the land unsuitable for further profitable cultivation with a succession of annual crops. There were no appreciable adverse changes in soil structure and the factors listed as being limiting for the continuance of cultivation were weed growth, insufficiently-burnt stumps which begin to shoot up in a year or so, the lack and impracticability of tillage and, in some areas, soil erosion.

With regard to the minimum interval between successive cultivation, it was pointed out that the crops depend for their successful growth on the increased availability of N and ash resulting from burning and the elimination of weed growth by the canopy of trees. This interval would thus be governed by the rate of growth of the latter, both in respect of height and density and would therefore vary in different districts.

Disadvantages of the Bush Fallow Rotation and causes leading to its failure

Previously it was pointed out that with a bush fallow rotation system of agriculture, increases in population pressure on a limited area of land lead to a reduction of the fallow period. This is the fundamental cause of failure of this type of subsistence agriculture to maintain soil fertility and thereby crop yields. As the cropping intensity is increased so the effective regeneration of natural vegetation is reduced,

tree species fail to become re-established, and annual plant species, mostly grasses, begin to dominate the fallow. Grass species once established in a fallow can spread and dominate an area, usually with the asssitance of fire, with surprising rapidity even in the tropical rainforest, and with their establishment is usually associated a decline in productivity of the soil. Fires which are either intentionally or unintentionally started in the grass-dominated areas of a bush fallow merely serve to accelerate the establishment of the grasses by killing out the tree species which may become re-established from either coppiced stumps or seedlings. In this way, large areas of the tropics have had their climax vegetation changed from one of tropical rain forest, evergreen seasonal forest or mixed deciduous woodland to a present day climax vegetation of grassland savannah. The resultant effect on leaching of this conversion of tree fallow to grass fallow is debatable. It is often claimed that in the absence of deep-rooted fallow trees, leaching becomes more intense so that mineral nutrients are rapidly lost from the surface soil horizons and the return of mineral nutrients accumulated in the lower horizons of the soil profile ceases. However, leaching losses may well be less under a grass fallow, firstly because of increased surface run-off, with the associated increase in erosion, and secondly because of repression of nitrogen mineralization by grasses, resulting in a low level of nitrate nitrogen. With relatively few anions in the soil solution, only low leaching losses are possible.

Referring to the above problems, Nye (1957), although defending bush fallow rotations in forest regions, clearly pointed out that the system is only satisfactory where there is sufficient land available for fallows of the necessary length and suggests that, where the problem of land scarcity occurs, the only answer, short of re-settlement, lies with fertilizers. Further, the bush fallow rotation is quite unsatisfactory in the grassland regions of Northern Nigeria where grasses colonize abandoned land only slowly and are almost invariably burned annually, exposing the soil to severe erosion by the storms of the early rains. In this and other regions of savannah the shortage of land has become an acute problem and the fallow period is not

PLATE 2.—*A pattern of bush fallow rotations in Sierra Leone.*

long enough to maintain more than a low level of fertility. Numerous fertiliser trials carried out in areas from Lake Chad to Dakar have indicated that savannah soils which are intensively cropped are short of phosphates. There are no, or only slight, responses to calcium and potassium or the trace elements in these areas so the purpose of fallowing is largely to restore the level of available phosphate in the topsoil, although the high C/N ratio of the grass must lead to a type of humus which maintains only an exceedingly low level of nitrogen in the soil.

On the other hand it is reported from Sierra Leone, which has an annual rainfall of 95 in. to 130 in. with a wet season from May to October and a marked drought in January and February, that grassland areas can be farmed satisfactorily if a sufficiently long fallow is used (Deighton, 1949). The original vegetation over the whole of Sierra Leone was forest, but now approximately the southern half of the protectorate supports forest or regrowth, and the northern half is tall grassland or tall grass-orchard bush savannah. The normal method of farming in the forest or regrowth areas is to fell the trees, burn them and take one crop of rice. Cassava is usually interplanted and this matures in the following year. The coppiced tree stumps are allowed to grow up again. In general, seven to nine years regeneration will adequately maintain soil fertility and prevent erosion provided the slope is not too steep. With a shorter period of bush fallow there is a rapid degradation to thin scrubby bush mixed with *Chasmopodium, Imperata* and *Andropogon* grass species and crop yields decrease greatly. In the northern part of the protectorate, where forest has been almost completely replaced by grassland, it has been found that these grasslands can be farmed periodically (with a five to six-year fallow) without any *further* degradation and there is nothing to suggest that grassland soils are not as good as forest soils for periodic arable cultivation, in fact there is some reason to think they are better.

In south-eastern Nigeria, in the Provinces of Ontisha and Northern Owerri, the deleterious effects of increased population and hence decreased fallow periods on forest regeneration and crop yields have been reported (Grove, 1949). The soils of this area belong to a series known as "Acid sands" and vary in texture from coarse sandy clays to loamy sands but with a topsoil which is always loose and sandy. Annual rainfall is 66 in. to 80 in. with a marked dry season between November and April and the mean annual temperature is 80°F., seldom falling below 60°F. or rising to 100°F. Population density within small areas exceeds 1,500/sq. mile and over the whole area there is an average of less than two acres of land to each of the two million inhabitants. Present-day climatic conditions indicate that these sandlands would naturally come within the rain forest or tropical dry forest vegetation belts, forest relics being found in native villages and isolated districts. To-day the area consists of derived savannah or village oil-palm bush. Increase in population and a decrease in the cycle of shifting cultivation has resulted in the development of a soil which is thoroughly leached and contains few available plant nutrients. Gully erosion and sheet erosion in many places is extremely bad. In the open farmland the fallow period has been reduced to as little as two years. Yams will not grow on the severely-degraded soils but cassava is the staple food. Attempts to establish leguminous cover crops on soils which are loose and sandy on gentle slopes, hard and bare on steeper slopes, badly dried out during four months of the year, and intensely acid, even at the surface have failed. The most successful fallow crop tried is *Acioa barteri,* the roots of which penetrate to more than 16ft. and which has a heavy leaf fall. After six to ten years on these soils the bushes reach a height of about ten feet.

The disadvantages of a bush fallow rotation have been somewhat differently criticised with reference to the Belgian Congo (Tondeur, 1955). Here the system has been described as the greatest obstacle to the immediate increase of agricultural production and the conservation of the production potential for the future in the form of soils and forest, although, as will be shown later, the basis of the biggest experiments on subsistence agriculture in this region is a modification of the bush fallow rotation known as the "Corridor system". By using the bush fallow rotation it is claimed, African farmers are not induced to intensify their agriculture or to undertake long-term improvements of the land. The periodic moves to a new village site also have the effect of discouraging the accumulation of material wealth and of making professional differentiation and specialization more difficult. A further charge is that soils may be degraded as a result of a reduction

in fallow periods due to increased population pressure or the introduction of cash crops.

Again in East Africa the system has been criticised (Eggeling, 1949), and it is claimed that many areas in this region are so heavily populated that there is an excessive pressure on the land resulting in destruction of vital cover, insufficient rest after cultivation, soil deterioration and erosion In fact, it has been stated that there is not a single country in tropical Africa where recent and continuing destruction of forest cannot be noted.

Under conditions of peasant farming in the Northern Range foothills of Trinidad, the effects of bush fallow rotations have reached serious proportions (Cater, 1939). Crops commonly planted are maize, tomatoes and chives, none of which have much effect in decreasing the speed of surface run-off of water which is not absorbed by the soil. Crops are usually harvested within six months of planting, and, although a second and sometimes third crop is grown on the same area, the land is often abandoned after one crop when erosion and the needs of the crop have exhausted the fertility of the soil. The abandoned land reverts to bush through the invasion of plants from neighbouring areas of secondary growth and the coppicing of stools not destroyed by fire. There is, however, little land carrying scrub older than four or five years and it appears that under the pressure for land the fallow period is being drastically reduced (Carne, 1949).

Two experiments in which the effects of intensified cropping on soil fertility have been studied are reported in the literature.

At the Kumasi Investigational Station, Ghana, tests were made between 1923 and 1928 of a prescribed sequence of foodcrops on ten plots, each one-quarter acre in area, receiving an annual rainfall of approximately 60 in. with a marked dry season from November to February and a break in the rains in July and August (Auchinleck and Hunter, 1928). Five plots were planted with cassava, maize, okra, groundnut and yam, one crop being grown continuously on each of the five plots, and on the remaining five plots the above crops were grown in rotation, each plot being started at a different point to give replications in time. Otherwise there was no statistical design or replication of treatments.

The results of this trial indicated that :—

1. Cassava, groundnut and maize can be grown for six years in succession in the field.
2. The productivity of the plots lessened when one crop was grown for six years in succession.
3. Productivity lessens at a slower rate when other crops are grown between two recurrences of the same crop.

The second experiment involved a study of soil fertility over six years (1949-1955) at the Yambio Experimental Farm in the Zande district of the Sudan (Anthony and Willimott, 1956). The Station is located on the Nile-Congo divide, 2,400 ft. above sea level, with an annual rainfall of 56in. (three dry months December to February) and on lateritic soils which have a ferruginous loam to sandy loam surface horizon with good crumb structure overlying a red clay subsoil with varying amounts of pea iron gravel. The climax vegetation in recent times was probably high forest but this has almost entirely been replaced by grass woodland as a result of fire and to a lesser extent cultivation.

Comparisons were made between the rotations shown in Table II.

TABLE II

Crop Rotations—Yambio

Year	Rotation A	Rotation B	Rotation C
1949	Cotton	Groundnuts/Eleusine	Maize/Eleusine
1950	Groundnuts/Eleusine	Cotton	Cotton
1951	Cotton	Sesame	Groundnuts/Eleusine
1952	Groundnuts/Eleusine	Lagenaria/Eleusine	Cotton
1953	Cotton	Sesame	Groundnuts/Eleusine
1954	Groundnuts/Eleusine	Sesame	Cotton

Each of the above three rotations was represented by three plots in each block of a strip of land 1,250 metres long and 50 metres wide containing 25 blocks (Diagram I).

DIAGRAM I

Each of the twenty-five blocks was divided as shown in sixteen plots, seven of which were allowed to revert immediately to bush after clearing, the remaining nine being used as shown for the three rotations. Of the three plots under a particular rotation, one was allowed to revert to bush after cropping for two years, the next after cropping for four years and the third after cropping for six years.

In the fourth year of the trial the three main crops, cotton, groundnuts and eleusine, all showed a fall in yield, this being most pronounced with groundnuts and eleusine. Cotton yields, although down, were maintained at what was considered an economic level into the sixth year, but the other two crops by this time were almost complete failures. Soil analyses indicated that differences between the N content of the soil from plots under the different treatments were not striking. Progressively lower values of total nitrogen with increasing periods of continuous cropping were clearly shown on two blocks, but not on another block with a high incidence of gravel.

The decline in yields of eleusine and groundnuts from uneconomic levels after the third year of continuous rotational cropping to a level amounting to practically complete crop failure in the sixth year is a clear vindication of the local practice of bush fallowing after two or three years' cropping. It is claimed that the soil data obtained strongly discount the possibility that this decline in yield was due to exhaustion of soil nitrogen, but the only determinations reported were of total soil nitrogen and tests with application of nitrogenous fertilisers might have shown deficiency of nitrate.

The study of vegetation regeneration after cropping showed that after two years' cropping, bush regeneration in the fallow was rapid and grass species were rapidly suppressed. With four and six years' cropping the stump population suffered some mortality. *Imperata cylindrica* dominated the fallow in the early years and after four years' cultivation, regeneration of woody species can be expected to be slow.

Experiments to determine the Optimum Length of Bush Fallow and Comparison with Planted Tree Fallow

The failure of the bush fallow to maintain soil fertility for subsistence agriculture, with increasing reduction of the fallow period resulting from shortage of land and the use in some areas of a planted tree fallow, has led to some investigations of the optimum fallow period required to maintain soil fertility and comparisons between the effectiveness of bush fallow and planted tree fallow for this purpose.

Reference has already been made to the use of the Rosaceous tree *Acioa barteri* in Southern Nigeria which is planted as a fallow crop on the leached acid soils of low fertility in this area (Grove 1949). In Sierra Leone experiments have been conducted to study the possibilities of hastening regeneration processes under bush fallow by cultivating specially-selected forest seedlings, but at the same time not unduly interfering with the normal growth of coppiced trees on and in cultivation (Dougall, 1948). Four forest species have been tested

Terminalia invorensis
Sarcocephalus diderichii
Tarriettia utilis
Gmelina arborea.

The only seedlings readily established were those of *Gmelina arborea.*

A noticeable feature of the intensive subsistence agriculture practised in the Chimbu region of the Highlands of New Guinea is the inclusion

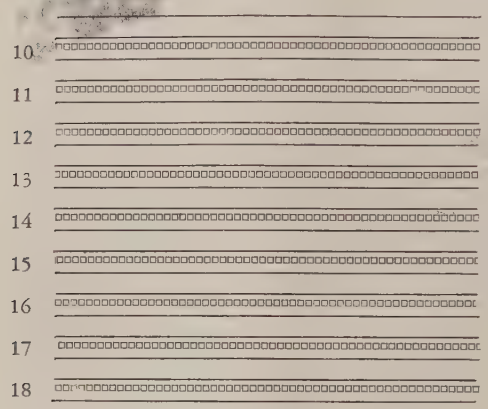
PLATE 3.—*Casuarina grove in the Chimbu area of New Guinea.*

of Casuarina trees in the rotation (Barrie, 1956). The trees are planted in the food gardens at the same time as the planting of the last and second-last rotations of the cropping cycle and are allowed to mature and remain for approximately ten to twenty years. The duration of the fallow period under the *Casuarina* cover is determined by apparent soil fertility and the area of land owned by the individual. When the garden land is required again the Casuarinas are used, firstly, to construct a pig-proof fence around the garden area. Other uses include building material and firewood.

By far the most comprehensive investigations into the conservation of fertility with bush fallow and the optimum fallow period have so far been conducted at research stations in the Belgian Congo although an experiment has been started at Aiyinasi in the tropical rain-forest region of south-west Ghana to determine the optimum period of bush fallow required (Anon, 1955-1956). In the Central Congo Basin the indigenous or "Bantu system" of agriculture was one of shifting cultivation or bush fallow rotation and initial agricultural research was aimed at completely modifying this apparently-wasteful method of cropping by the application of European farming techniques. At several research stations experiments were undertaken which involved cutting and clearing of all forest, including stumps, deep ploughing, short-term grass or leguminous fallow, organic manures and artificial fertilisers. Some of these experiments, such as deep ploughing with leguminous fallow, always had deplorable results and, consequently, in recent years agricultural settlement schemes based on the original "Bantu system" of bush fallow, which alone seemed to safeguard and regenerate soils, have been developed with certain modifications (Coene, 1956).

One such settlement scheme known as the "Corridor System" (Kellog and Davol, 1950-1951) consists of a series of corridors some one to two miles long and 300 ft. wide which are laid out so that some are in forest, some reverting to forest, some in crops and some being brought into cultivation as illustrated in Diagram. II.

DIAGRAM II



The strips are numbered according to the scheme of clearing and hence with a short cropping cycle of three years strip ten will be cleared when strip one is in its seventh year of fallow and strip two in its sixth year of fallow. These alternating strips provide a protection against plant diseases and the spread of bush fires which is always possible in young fallows where grasses are present. The strips are placed with their long axis East-West so as to provide maximum light for crops and, although they may be of any length over 200-300 yards, they should be no more than 300 yards wide. This maximum width is stipulated so that the forest is close enough on the North and South boundaries of the fields abandoned after cropping to provide a source of mother trees which will promote rapid regeneration of forest fallow.

Certain observations and preliminary studies in the Belgian Congo have indicated that the fallow period should be of some twelve years' duration with a three-year cropping period giving a crop-fallow cycle of fifteen years. Further experiments in progress are designed to give more accurate data on these figures. Numerous other experiments have been conducted to determine the best cropping system to

PLATE 4.—*Young coffee bushes established in place of foodcrops in a "Corridor" strip.*

be used (Coene, 1956), but during a visit which the author made to the Belgian Congo in the latter half of 1959 it was evident from discussions with research workers at Yangambi that there was no longer any emphasis on the use of the "Corridor System". The establishment of mixed farms employing a rotation of fodder grasses and foodcrops, cattle being grazed on the grass fallow, is now considered to be of greater value.

For the comparison of bush fallow with a planted-tree fallow the long-term rotation trial described by Toovey (1953) was established at W.A.I.F.O.R. in 1947 to compare the merits of natural bush fallow and *Acioa barteri* in restoring fertility. Fallow periods of two, three, four or five years of *Acioa* and four years of bush fallow alternating with a two-year cropping period are being tested. The *Acioa barteri* is planted in rows eight feet apart and cut down and burned at the end of the fallow period. The foodcrops are planted between the rows of stumps and when the land is abandoned after two years the coppice shoots from the stumps are sufficiently developed to give a good cover. Early in the experiment comparisons were made between the nutrients stored in the *Acioa* fallow and those stored in the natural bush fallow to find out whether there was any obvious chemical advantage in using a planted fallow without having to wait the several years necessary before yield comparisons would be valid (Nye and Hutton, 1957).

As the growth of *Acioa* in the trial was erratic, due to difficulties of establishment, comparisons were made between a well-established *Acioa* which had grown for two years of cropping and a fallow period of four years and a natural fallow plot undergoing the same cropping cycle.

The results of analyses indicated that the nutrients stored by *Acioa* are no greater in general than those by the natural bush fallow owing to the low nutrient content of the wood that forms the bulk of the *Acioa*. In all it contained about half as much P and K as the natural fallow but rather more of the divalent ions Ca and Mg. Since phosporus and potassium are the elements most likely to be deficient for annual foodcrops the results did not encourage the idea that an *Acioa* fallow would prove superior to natural regeneration from the nutrient standpoint, at any rate on the more fertile areas of Tertiary Sandy soils where there is rapid growth of natural fallow. However it has previously been pointed out (Grove, 1949) that there are vast areas in Southern Nigeria at least where *Acioa* is almost the only fallow crop which can be grown and is undoubtedly of great value. Further there are also many areas of grassland where regeneration of tree species has long ceased and where *Acioa* could prove to be a successful fallow crop.

Early yield figures (Toovey, 1957) tended to support the evidence obtained from the chemical analyses in that they indicated very little difference between the yields from plots with different fallow periods (Table III).

TABLE III

W.A.I.F.O.R. Main Station Experiments 20-2 and 33-5 Yields of Ware Yams, November, 1956

2 years *Acioa* fallow	(3rd cropping)—2,414 lb./acre
3 years *Acioa* fallow	(2nd cropping)—3,022 lb./acre
4 years *Acioa* fallow	(2nd cropping)—2,476 lb./acre
4 years bush fallow	(2nd cropping)—2,464 lb./acre
5 years *Acioa* fallow	(1st cropping)—2,920 lb./acre

By 1957, yield figures pointed to a slight superiority of the four-year *Acioa* fallow over the four-year bush fallow and fertility was being maintained (Gunn, 1958). The yields of the three crops grown which are summarized by treatment in Table IV were obtained by adding the weights of produce together from groups of plots of the same fallow treatment and although the final analysis or results will be carried out in a different way some idea may be obtained of the relative value of the various fallow periods.

TABLE IV

Crop Yields—W.A.I.F.O.R. Experiments 20-2 and 33-5

Fallow	Experiment 33-5			Experiment 20-2			Total
	Maize	Cassava	Yams	Maize	Cassava	Yams	
2 year *Acioa*	512	5,473	4,626	410	6,812	4,478	22,311
3 year *Acioa*	369	7,674	4,829	522	6,293	5,844	25,531
4 year *Acioa*	502	7,470	5,300	507	7,145	4,129	25,052
4 year Bush	551	8,812	4,783	512	4,868	5,286	24,812
5 year *Acioa*	558	9,851	4,917	558	6,616	5,077	27,577

It is suggested that these figures indicate that the longer fallow periods under *Acioa* are advantageous and that an *Acioa* fallow has greater soil-regenerating value than a bush fallow but without a statistical analysis of the results it is difficult to come to any conclusions. Certainly the five-year *Acioa* fallow seems the most satisfactory and four-year *Acioa* fallow may be better than four-year bush fallow but nothing can be definitely stated from these results. However, if the *Acioa* fallow proves satisfactory there is the possibility that both growing the foodcrops between the rows of *Acioa* and coppicing the *Acioa* could be mechanized. Such mechanization would, of course, require testing against continually cropped and fertilized plots.

SECTION II

The Functions of Leguminous Cover Crops and Green Manures

With the realization that the bush fallow rotation could only maintain fertility for subsistence agriculture in sparsely populated areas and that serious problems of food sufficiency were arising and would arise as human and stock population pressure increased, most Departments of Agriculture in the tropics, together with other research organizations, turned their investigations towards the development of alternative farming systems for subsistence food crops. Included among these were investigations based on the partial or complete replacement of the bush fallow with leguminous cover crops and green manures. This was as a result of the wealth of evidence from temperate countries pointing to the beneficial results which were obtainable by the use of legumes in rotations.

Many authors have written on the advantages of cover crops and green manures as a means of building up soil nitrogen, increasing soil organic matter, protecting the soil from the effects of rain and sun, improving soil structure and bringing to the surface mineral nutrients leached down the profile, much of the earlier work being admirably reviewed by Pieters (1927). A typical list of the alleged advantages of cover cropping and green manuring (Joachim, 1931 and Mundy, 1930) reads as follows :

1. Increase in the organic matter of the soil, especially the humus content. By ploughing in green manures valuable organic matter is added to the soil which, on decomposition, forms humus.
2. The humus absorbs water and mineral constituents of the soil and regulates the supply of these and of nitrogenous substances to plant roots.
3. Humus improves texture and tilth, breaking up heavy soils and binding together lighter soils and rendering them better able to withstand drought.
4. Humus is directly or indirectly the main source of nitrogen in the soil and it stimulates the activity and number of soil micro-organisms which are responsible for all the organic changes taking place in the soil.
5. Increase in the nitrogen content of soils. Green manuring, by the choice of suitable leguminous cover crops, can add appreciable supplies of nitrogen to the soil.
6. Conservation of the soil and its fertility and the improvement of its physical condition by the prevention of erosion and protection from leaching.
7. Cover crops are effective in taking up mineral nutrients which have been leached down the profile and re-supplying the surface soil with nutrients in a quickly-available form.

8. A cover crop protects the soil from the beating action of heavy rain and excessive heat of the sun.
9. Firmly established cover crops smother weeds and provide an economy in weeding costs.

In a more-critical appraisal of these commonly listed advantages, green manuring has been stated to have the following effects (Russell, 1958). It may increase the organic matter content of, or the available nitrogen in, the soil ; it may reduce the loss of mineral nitrogen by leaching ; and it may concentrate nutrients likely to be deficient in the surface soil and have them there in a readily available form. Green manuring cannot normally confer all of these benefits simultaneously and it may confer none of them.

Nitrogen

The importance of legumes in temperate agriculture as a method of building up levels of soil nitrogen has been well known for many years and in Australia it has been possible to develop millions of acres of light land and heavy soils for wheat and sheep farming through the use of subterranean clover in combination with dressings of superphosphate to overcome the deficiencies in these soils of nitrogen and phosporus. This ability of legumes to build up levels of soil nitrogen results from the fixation of atmospheric nitrogen by bacteria of the genus *Rhizobium* living in symbiotic association with the roots of the legumes. The bacteria are found in many soils as free-living organisms but the developing roots of legumes stimulate their rapid multiplication in the rhizosphere. This is followed by the secretion of indolacetic acid by the bacteria causing a curling of the root hairs and eventual penetration of some of these root hairs by " infection threads " along which bacteria pass into the cortical cells of the root. Within the root, the development of tetraploid cells takes place close to the lateral root initials and these are stimulated to divide and start the growth of nodules which are considered to be highly-modified lateral roots.

Fixation of atmospheric nitrogen by the bacteria begins after they have multiplied and grown to large forms within the nodules. The amount of fixation is roughly proportional to the total volume of bacteria, and the amino acids produced are rapidly translocated to other parts of the plant. Hence, it is in this manner that atmospheric nitrogen is stored in leguminous plants as amino acids and with the growth and eventual death of the plant is transferred to the soil, resulting in an increase in the level of soil nitrogen.

Although these increases in soil nitrogen have been proven many times under temperate conditions there still remains a certain amount of disagreement amongst tropical workers as to the functioning and efficiency of legumes in tropical soils.

Both the legumes and their associated Rhizobia are considered to have evolved at the same time in the Upper Cretaceous period when the occurrence of highly leached acid soils under tropical climatic conditions was much more widespread than at present, extending further north and south of the equator (Norris, 1956). Examination of the global distribution of present day Leguminosae shows that the greater number of both genera and species are still tropical in occurrence and tolerant of acid soils and Greenland (1959) has pointed out that in the tropical rain-forest areas of Ghana about 50 per cent. of the species occurring on oxysol soils (pH 4-5) are leguminous species, whereas in drier areas on ochrosols (pH 6-7) only five per cent. of the species are legumes. Some genera such as *Trifolium, Medicago, Vicia,* and *Lupinus* although originating in a tropical environment have become adapted to temperate climates and lime rich soils and these are the ones which have been studied most thoroughly and used most extensively, the misconception has developed that legumes are essentially plant species of temperate climates. These temperate climate legumes have become specialised with particular requirements for certain strains of Rhizobia unlike the tropical legumes which can associate with several strains of Rhizobia. Hence the hypothesis is advanced that the " cowpea " group of nodule bacteria associated with tropical Leguminosae represents the ancestral condition and is the type of the genus *Rhizobium. Rhizobium* associated with such genera as *Trifolium* is atypical having a high requirement of Ca for growth and a specialized requirement for a host plant. Norris (1956) points out therefore that poor nitrogen fixation by tropical legumes or poor nodulation may be due in part to the erroneous conception that calcium is required for optimum growth of legumes in the tropics as in temperate climates and the subsequent liming of tropical

soils. However there is some evidence that effective nodulation of legumes does occur in the tropics on acid soils although this does not necessarily mean that the nodules are functional in nitrogen fixation. Further, it has been pointed out that of over 11,000 species recognized in the Leguminosae there are only about 1,200 which have been examined for presence or absence of nodules and of these, 133 or about nine per cent., apparently never bear nodules at all.

A study of the degree of nodulation of *Phaseolus vulgaris* (Masefield, 1952) revealed that plants growing in Nigeria had a lower weight of nodules than those growing in England. Single observations on groundnuts, cowpeas and a few other crops in Nigeria

PLATE 5.—*Plots under peanuts in a crop rotation experiment at Akure, Nigeria.*

showed that they had a lower range of nodule weights than field beans, peas and *P. vulgaris* in England though with some overlapping between the higher Nigerian and lower English figures. The value of this work is however questionable in view of the fact that the incidence of nodulation in the tropics varies with season, nodules often being shed in the dry season (Greenland, 1959).

Experiments at Peredeniya (Joachim, 1931) have indicated that by growth of green manures the nitrogen contents of soils are maintained while those of controls with no legumes have shown an appreciable fall.

An experiment conducted at the Scott Agricultural Laboratories in Kenya (Gethin Jones, 1943) compared the total nitrogen status of the soil under a cover of the indigenous legume *Glycine javanica* for nine years with soil under clean cultivation or a true soil mulch. Rainfall at the site averages 36.61 in. per annum and the soil is a Kikuyu lateric red loam. Plots under the cover of *G. javanica* showed a total gain of total soil-nitrogen equivalent to 1,164 lb. per 9 in. acre over the nine year period. To this can be added the amount of total nitrogen in the cover crop and leaf litter which would temporarily enrich the soil if turned in and this was equivalent to 400 lb. per 9 in. acre. Therefore when the cover is newly ploughed-in the total soil nitrogen would appear to be temporarily enriched by 1,500 lb. N per 9 in. acre which is equivalent to sixty or

seventy tons of good compost. On the other hand the plots under clean cultivation showed a loss of total nitrogen over the same period equivalent to 218 lb. per 9 in. acre.

As a conclusion from the foregoing comments it can be seen that the assumption by earlier workers that the use of leguminous cover crops and green manures will increase levels of soil nitrogen under tropical conditions must be treated with some caution. Sufficient evidence has been accumulated to show that soil nitrogen levels are raised in temperate soils but there is a great need for further study of the functioning of legumes under tropical conditions, even though the greater number of legumes are tropical in distribution and tolerant of acid soils. Only a small percentage of the Leguminosae have been examined for presence or absence of nodules and of these some apparently never nodulate. Even so, nodulation of legumes does occur in tropical soils, there is evidence that soil nitrogen levels are raised by leguminous cover crops and poor nitrogen fixation by legumes may have been due to the effects of liming as a result of the misconception that temperate legumes and their associated Rhizobia, with a high lime requirement, are typical rather than atypical.

Organic Matter

Much of the earlier literature continually refers to the beneficial effects of green manures in building up levels of soil nitrogen *and* organic matter or humus but by now it has been well established (Russell, 1958) that green manures, when properly used, will either increase the humus content of the soil *or else* the supply of available nitrogen in the soil, but rarely can they do both at the same time. Therein, green manure differs from well-made farmyard manure because the humus content of the soil only appears to be increased appreciably if material fairly resistant to decomposition is added to the soil and resistant plant material is typically low in nitrogen with a wide C/N ratio. The available supply of nitrogen is only increased if readily-decomposed material high in nitrogen (low C/N ratio), such as young green plants, are decomposing. Thus the effect of a given crop as a green manure on levels of soil organic matter and soil nitrogen depends on its maturity when ploughed under. In most parts of the world, green manuring has been applied more successfully to increasing the available nitrogen supply than the humus content of soils. However the process may be relatively ineffective, particularly under warm moist conditions, because, with the addition of an easily decomposable material to the soil the activity of the micro-organisms is so stimulated that they not only attack the material added to the soil but also some of the more resistant organic matter in the soil. If the subsequent crop does not become sufficiently developed to take up nitrate soon after it is released, the nitrate will be leached out of the soil. In this respect a study was made of soil nitrate nitrogen levels, in four layers to a depth of 24 in., for a period of seven months after ploughing in four perennial tropical legumes at South Johnstone on the wet tropical coast of Queensland (Schofield, 1945). The legumes used were *Calopogonium mucunoides, Centrosema pubescens, Pueraria phaseoloides* and *Stylosanthes guianensis,* ploughed in after 18 months growth. Nitrate nitrogen values rose rapidly in all plots to a peak level approximately four months after the covers were ploughed in but levels remained fairly high for the duration of the experiment which was concluded just before the monsoonal wet season rains. During the seven months an extremely high positive correlation was found between rainfall and leaching of nitrate nitrogen. *P. phaseoloides* which gave the highest levels of nitrate nitrogen had produced the greatest amount of green matter before turning under.

Structure

If levels of soil organic matter and hence humus are increased by a green manure at a late stage of maturity, with a wide C/N ratio and hence fairly resistant to decomposition then the structure of the soil will usually be improved and the beneficial effects attributed by the earlier writers to humus will accrue. A mass of experimental evidence has been accumulated by investigators in temperate areas to show that a close relationship exists between the organic matter content of the soil and the water stability of aggregates, the one increasing with the other, but some digression from this correlation has been found in South Africa (Klintworth, 1954). In a structure experiment at Grootfontein College of Agriculture, Cape Province, it was found that :

(*a*) In the case of perennial fodder crops (*Festuca arundinaceae, Pennisetum purpureum* and Lucerne) a positive correlation

between the water stability of the soil aggregates and the carbon content exists.

(*b*) In the case of annual crops (*Vigna sinensis* dug in as green manure, *V. sinensis* removed as hay, kraal manure and maize) the relationship is reversed and structure decreases with increase in soil organic matter. This has been explained by the fact that soil structure is not a function of the total organic matter content but rather depends on the activity of the micro-biological population and hence in green manured soil, when the activity of the micro-biological population is stimulated to such a degree that not only is the green manure totally decomposed but also some of the organic matter, the loss in soil organic matter results in an increase of the autolytic by-products of decomposition and a consequent increase in structure.

Therefore it is apparent that, as with the previously listed factors, the conclusions arrived at for temperate conditions are not necessarily applicable although the overall effect of the green manure in the above experiment was still an improvement in soil structure.

Erosion

The use of a cover crop on the soil will obviously prevent erosion in comparison with bare plots, as has been shown at Peredeniya (Joachim, 1931) and considerably reduce the loss of structure, leaching and loss of organic matter by protecting the soil from the effects of rain and sun.

SECTION III

Crop Rotations using Legumes as Cover Crops or Green Manures

From the preceding sections of this paper the many perplexing problems of the use and conservation of the supply of plant nutrients indigenous to soils of the tropics have become evident, the problems arising in designing land-use practices which do not permit excessive losses of plant nutrients or a marked decline in productivity, during the cropping interval. Numerous attempts have been made to develop systems of land use for the widely-varying conditions existing in the tropics and sub-tropics including the use of ley farming, ranching, mixed farming, market gardening, permanent tree crops, modified shifting cultivation and crop rotations with legumes but it is only the results obtained from experiments on this latter system which will be reviewed here.

Despite the tremendous amount of work which has been carried out in temperate countries on the use of legumes in various farming systems and the abundant evidence accumulated pointing to the beneficial effects obtainable from this practice and despite the numerous papers which have been written on the use of legumes in the tropics as cover crops or green manures, outlining what their effects should be, one finds on reviewing the literature that surprisingly little experimental work of any value has been conducted on the problem of replacing the bush fallow with a rotation based purely on the use of leguminous fallows.

A Survey of the Results from short-term Rotation Trials

It is proposed to review in both this section and the following section on long-term rotation trials the results obtained from various tropical areas in order of decreasing rainfall as it is apparent from the preceding review on the functions of cover crops and green manures that rainfall is one of the most important factors in determining the effects of these legumes assuming adequate growth and nodulation.

Firstly, in Sierra Leone, at the Njala Experiment Station, an experiment was conducted to test the effect of establishing a leguminous crop through an economic cereal crop which in this case was rice (Dougall, 1948). The Station has a rainfall of 110 in. per annum with one wet season from May to November. Elevation is between 400 and 500 ft. above sea level and the soil type is a very deep, acid (pH 5.2) reddish-brown ironstone gravel. The plots used for the experiment had supported secondary bush for more than eighteen years so that to begin with, the site for the experiment was quite unsuitable in that fertility of the soil mush have been very reasonable after such a long bush fallow. A one-acre block was cleared, burned, ashes incorporated and four quarter-acre blocks marked out to which the following treatments were applied :

1. Rice and *Pueraria phaseoloides* sown at a rate of 12 lb. per acre
2. Rice and *Tephrosia candida* sown at a rate of 8 lb. per acre

3. Rice and Groundnuts (no details of sowing rate)
4. Rice (Control : no legume interplanted)

Yields were as follows :

1. 1,628 lbs. padi per acre
2. 1,788 lbs. padi per acre
3. 1,462 lbs. padi per acre
4. 1,376 lbs. padi per acre

It was concluded that interplanting of legumes may be of benefit to the crop but the experiment must be criticized on the grounds that :

(*a*) It was an unreplicated trial. The total area of one acre was large enough for a trial of this nature with only four treatments had it been subjected to a suitable statistical design with replications but without this the results are of little value.

(*b*) As mentioned above the area used for the trial was probably reasonably fertile.

(*c*) Any benefit due to the legumes would not be shown to any extent in the concurrent rice crop. However, it was intended that the cover crops be continued and followed by a test crop of Gold Coast cassava on all plots but no further results have been published.

Workers in the Belgian Congo have generally condemned the use of legumes in crop rotations under the climatic conditions of that country as a result of early experiments which were carried out under a policy advocating the replacement of the traditional system of agriculture with systems based on the application of technical principles suited to European agriculture At the Yamgambi Experiment Station, a trial using the following rotation was carried out (Tondeur, 1955).

Pueraria and *Calopogonium* for one year
Padi—1st season
Groundnuts—2nd season
Cassava—3rd season

The Station has an elevation of approximately 1,100 ft., a rainfall of 70 in. to 80 in. per annum, natural vegetation is tropical rain forest and the soil is classed as yellow ochre sand derived from wind deposits, having a pH of 4.1 to 4.5 and organic carbon content of one to two per cent. in the humus horizon. Forest was cleared, stumps removed and burned followed by deep ploughing and sowing of a mixture of *Pueraria* and *Calopogonium* or a cover crop for one year. At the conclusion of the cover crop phase, deep ploughing was again carried out prior to planting the foodcrops.

With this system it was found that rice yields fell from 2,110 lbs. per acre to 506 lbs. per acre in three years, groundnut yields fell from 1,230 lbs. per acre to 170 lbs. per acre in five crop seasons and cassava yields fell from eighteen tons to twelve tons per acre in the second cycle of the rotation and it was concluded that such a decline in yields definitely condemned this form of intensive agriculture. No explanation for this decline in yields is given, but it is suggested that under the warm and moist conditions pertaining in this area, the breakdown of the organic matter from the cover crop would be rapid with an initial release of large amounts of nitrate nitrogen and other mineral nutrients, followed by rapid losses through leaching. Coupled with this, the activity of the micro-organisms could have been so stimulated by ploughing in the cover crop that the soil organic matter built up under the rain forest would be attacked and rapidly broken down, resulting in a further loss of mineral nutrients. In addition the fact that the felled bush was burned rather than left to rot would again be a factor contributing to fairly rapid disappearance of organic matter from the soil.

Again in the Philippines, where much of the natural vegetation is tropical rain forest and rainfall generally exceeds 80 in. per annum, no beneficial effect has been derived from the use of legumes in simple short-term rotations. A rotation using corn and cowpeas compared with continuous cropping under corn on two quarter-acre plots gave the following results shown in Table V (Francisco, 1918).

TABLE V

——	Continuous Corn	Corn and Cowpeas
1st Wet Season	1,758.5 Kilos	1,697 Kilos of Corn
1st Dry Season	474 Kilos	128.8 Kilos of Cowpeas
2nd Wet Season	1,405 Kilos	1,476.5 Kilos of Corn
2nd Dry Season	506.1 Kilos	220.1 Kilos of Cowpeas

The plots were not replicated but it is very doubtful if there is any significant difference between the comparative corn yields in the second wet season. One crop of cowpeas certainly did not maintain corn yields in that rotation. Whether or not the cowpeas were ploughed in as a green manure is not indicated.

From another experiment designed to test the effect of four green manures planted before a corn crop and ploughed under at flowering it was found that only one green manure gave any significant increase in yield of the following corn crop over the control (Barros, 1940). However, in a similar type of experiment conducted at the Imperial College of Tropical Agriculture, Trinidad (Measures, 1938) it was found that green manures did increase crop yields. Rainfall is approximately 60 in. per annum and the soil type is classified as a St. Augustine loam having a topsoil which varies from a loam to silty clay loam to clay loam, the texture gradually decreasing with depth to a sandy loam or gravel at about seven feet. The profile has free drainage, is acid throughout, and generally deficient in mineral nutrients (Chenery, 1949). Two green manures grown on plots separate from the experiment were used for the experiment, *Cannavalia* sp. and *Crotalaria juncea.* These were :

(*a*) Ploughed in green

(*b*) Ploughed in after wilting

(*c*) Burned and the ashes ploughed in

and these treatments were compared with a control in which no green manure was applied.

Maize and Soya beans following the above treatments as indicator crops gave yields which were significantly higher than the control for all three green manure treatments over the six-month cropping period. There was no significant difference between any of the three methods of application of the green manures, which indicates that decomposition of the green manures must have been fairly rapid to be comparable with the burned treatment and in fact as previously shown liberation of nitrate-nitrogen can reach a maximum within four months of ploughing in green manures (Schofield, 1945).

In Nyasaland a series of rotation experiments have been laid down over the years beginning with the simple type of rotation as conducted at Naisi Station around 1915 (Anon, 1915-1916). Here a comparison was made between :

1. Continuous maize
2. Maize and groundnuts (harvested)
3. Maize and velvet bean (dug in)

Plots were one acre each in area, no details of soil type or experimental design are given and rainfall is approximately 45 in. from November to April and two inches from May to October. The results showed that rotations 2 and 3 gave higher yields of maize but this could have been due to the effect of alternating the maize with a different crop rather than the same crop as was shown by later experiments (see below) or it may have been due to a beneficial effect of the legumes.

That a preceding legume crop does increase maize yields was shown by an experiment at Chitedze Station which gave the results shown in Table VI (Anon, 1954-1955).

TABLE VI

Rotation Experiment No. 4

Maize After Various Treatments—2nd Year

Maize After	Yield in lbs.	Grain/acre
Maize	1,665	(15)*
Groundnuts	2,900	(3)
Sunhemp	3,069	(7)
Velvet Beans	3,759	(6)
Sorghum	1,829	(8)
Bush	1,506	(3)

* Indicates the number of plots averaged for yield figures.

Rainfall is between 30 in. to 40 in. during the wet months from November to April and two inches to four inches during the dry months from May to October. Although no analysis is given there is an obvious effect on maize yields by the legumes, which were used as green manures, in comparison with bush fallow and sorghum. However in two further rotation trials, one at Chitedze and one at Tuchila (Anon, 1954-1955) it was shown that a preceding crop of tobacco was as effective as groundnuts on maize yields although with groundnuts some of the possible beneficial effect is lost by harvesting the crop (Tables VIIA and VIIB).

At Chitedze there was no significant increase in maize yields effected by a preceding crop of

TABLE VIIA

Rotation Experiment No. 2 Chitedze

Preceding Crop	Maize lb. Grain	Maize and Beans lb. Grain	Groundnuts lb. Kernel	Tobacco
Maize	2,872	2,288	618 *	411
Maize and Beans	2,915	2,295	551 *	409
Groundnuts	3,118	2,795 *	329	502 *
Tobacco	2,818	2,361	522 *	376
Mean	2,931	2,435	505	425
L.S.D.	381	442	121	83
Coeff. of Variation	11.6%	16.3%	21.8%	17.5%

* Indicates significant increases over the crop grown for two years running.

TABLE VIIB

Rotation Experiment No. 2. Tuchila

Preceding Crop	Maize lb. Grain	Cotton lb. Seed Cotton	Groundnuts lb. Kernel	Tobacco
Maize	2,394	719 *	133 *	659
Cotton	2,605	603	215 *	583
Groundnuts	3,280 *	727 *	52	718
Tobacco	3,651 *	727 *	209 *	646
Mean	2,983	694	152	652
L.S.D.	441	60	59	77
Coeff. of Variation	13.3%	7.8%	34.6%	10.6%

* Indicates significant increases over the crop grown for two years running.

either tobacco or groundnuts but at Tuchila, both tobacco and groundnuts grown as preceding crops significantly increased maize yields and cotton yields. Tobacco, cotton and maize were all better than groundnuts as a crop preceding groundnuts and generally, all crops gave better yields after a different preceding crop.

This, therefore, rather pointedly reveals the care which must be exercised in attributing yield increases after groundnuts, at least to a beneficial effect of the groundnuts as a legume when the result could be due merely to the effect of the groundnuts as a different crop to the one following and obtainable just as well with a crop such as tobacco. Further, the same argument may be applicable to legumes other than groundnuts.

At Lilongwe Experiment Station, rainfall 32.7 in. from November to April and 0.8 in. from May to October, two rotation trials were conducted to compare the various treatments as shown in Tables VIIIA and VIIIB (Anon, 1935-1937).

TABLE VIIIA

No. 1 Rotation Experiment. Lilongwe

Rotation	Year 1	Year 2	Year 3	Year 4
R1	Bush fallow	Bush fallow Burned	Millet 1,647 lb. Burned	Tobacco 3,428 lb.
R2	Sunhemp Dug in	Millet 611 lb.	Millet 1,480 lb.	Tobacco 3,957 lb.
R3	Groundnuts	Maize + Organic Matter 2,997 lb.	Millet 1,530 lb.	Tobacco 3,808 lb.
R4	Pigeon Pea	Pigeon Pea Burned	Millet 1,567 lb. Burned	Tobacco 4,286 lb.
R5	Sunhemp Not dug in	Millet 1,006 lb. Burned	Millet 1,240 lb. Burned	Tobacco 3,960 lb.
R6	Pigeon Pea	Pigeon Pea	Millet 1,403 lb.	Tobacco 2,970 lb.
R7	Bush Fallow	Bush Fallow	Millet 1,423 lb.	Tobacco 2,860 lb.

Year 3. Differences are significant as 1 > 4, 3, 2, 5, 6, 7
4 > 2, 5, 6, 7
3 > 2, 5, 6, 7

Year 4. Differences are significant as 4, 5, 2, 3 > 1, 6, 7
1 > 6, 7

TABLE VIIIB

No. 2 Rotation Experiment. Lilongwe

Rotation	Year 1	Year 2	Year 3	Year 4
R1	Bush Fallow	Tobacco 3,640 lb.	Bush Fallow	Tobacco 3,373 lb.
R2	Tobacco	Tobacco 2,687 lb.	Tobacco	Tobacco 3,337 lb.
R3	Soya	Soya 240 lb	Tobacco	Tobacco 3,293 lb.
R4	Sunhemp Dug in	Maize 2,240 lb.	Tobacco	Tobacco 3,620 lb.
R5	Pigeon Pea	Pigeon Pea	Maize + Organic Matter	Tobacco 3,477 lb.
R6	Cowpea Cropped	Maize 1,287 lb.	Tobacco	Tobacco 3,843 lb.

Year 2. R1 significantly > R2

Year 3. No results published

Year 4. No differences are significant

Results from the No. 1 Rotation Experiment indicate that new land brought in from a bush fallow which has been burned prior to cropping (R1) or a deep rooted legume fallow treated in the same way (R4) gives the best yields of millet, but without burning neither of these fallow treatments (R6 and R7) has any beneficial effect in comparison with the other one year legume prior to cropping treatments during the same period However in the fourth year tobacco yields indicate the outstanding effect from the two-year pigeon pea fallow although

why this should be so much better than the burned bush fallow treatment is difficult to say in the absence of details of the type of bush fallow growing on the plots. As both pigeon pea and bush were burned a yield response by the following crop could be expected and attributed to the ash added to the soil but as no details of the volume of material burned are available it can only be suggested that the bush fallow was a very light cover of possibly secondary growth and herbs and grasses whereas if the pigeon pea cover was dense the quantity of ash may have been so much greater that it was effective in the second following crop. Any nitrogen reserves built up by the pigeon pea fallow would be mostly lost by burning although contribution from the root system may have been effective.

The No. 2 Rotation Experiment showed that there was no significant improvement in yields obtainable by using a legume fallow as in R4, R5 and R6 in comparison with the use of a bush fallow as in R1 or continuous cropping as in R2 although where sunhemp was dug in as a green manure the yield was highest

Experiments such as these can hardly be evaluated in the absence of details, which are so noticeably lacking in much of the literature. For example the report on the No. 2 Rotation Experiment fails to mention

1. Climate
2. Soils
3. History of the plots on which the experiment was conducted
4. The type of bush fallow in R1 and its treatment prior to cropping
5. What happened to the plots in R2 and R3 between crops
6. Treatment of the pigeon pea in R5 before cropping and so on

A final experiment in Nyasaland, relevant to this section was one conducted at the Empire Cotton Growing Experiment Station at Chitala (Ducker and Hoyle, 1948) on a complex of residual and colluvial soils derived from schists and modified by admixture of soils derived from dolerite dykes. Mean annual rainfall on the Station over a period of 17 years was 33 in. nearly all of which falls in a well distributed pattern during the four months December to March. Temperature means vary from 90° maximum and 70° minimum at the beginning of the rains to 85° maximum and 60° minimum at the end of the rains with lower temperatures during the dry months. The rotations compared in the trial were :

1. Continuous cropping with cotton and maize
2. One-year pigeon pea fallow, cotton and maize
3. Two-years pigeon pea fallow, cotton and maize
4. Two-years elephant grass fallow, cotton and maize
5. Three-years elephant grass fallow, cotton and maize

Cotton yields revealed no signficant difference between rotations 3, 4 and 5, all of which were significantly higher and rotations 1 and 2. Maize yields showed rotation 5 to be significantly better than rotation 4, which was significantly better than rotation 3. This introduces the question of the value of grasses in comparison with legumes as fallows but it is not intended to elaborate this point in the present paper other than to say that there are many examples to be found in the literature where a grass fallow has had an apparently beneficial effect both on soil structure and on soil fertility The main point from the results is that a two-year pigeon pea fallow gave significantly improved yields over a one-year pigeon pea fallow and continuous cropping which was not the case in the No. 2 Rotation Experiment at Lilongwe where annual rainfall and distribution of rainfall are much the same.

The beneficial effect of a green manure crop on a following maize crop has been thoroughly demonstrated at Moor Plantation, Ibadan, Nigeria (Faulkner, 1934). Annual rainfall is 48.5 in. falling mostly in the rainy season from April to November with a break in August. The soils are fairly light showing, on mechanical analysis,. 50 per cent. to 70 per cent. coarse sand, 10 per cent. to 30 per cent. fine sand and less than 20 per cent. silt and clay. They contain less than 0.15 per cent. total nitrogen and pH varies from 5.7 to 6.7. A series of experiments were conducted using maize as the indicator crop and *Mucuna utilis* as the leguminous manure. Maize was planted at the beginning of the rainy season and followed by mucuna Mucuna was cut and dug in green before flowering, cut and left on the surface for four months over the dry season before digging in, allowed to mature and die and then dug in, cut and allowed to dry over four months and then burned and dug in, cut and burned at the

end of the rainy season and pulled out and carried from the plots at the end of the rainy season.

Results from all these experiments indicated that :

1. It makes little difference whether the leguminous crop is buried at the proper stage of growth or is allowed to produce its seed ; whether it is buried green or allowed to remain on the surface of the soil through three months of dry weather and then buried or whether it is burned *in situ*. However burning is the most convenient and probably the best method of disposing of the crop.

2. The benefit from a green manure crop is, under Ibadan conditions, largely exhausted by the next succeeding crop. In fact the after-effect of green manuring should not be regarded as something similar to that of organic manure in a temperate climate but rather as similar to that of soluble artificials. It is emphasized that these statements are believed to apply only to a strictly tropical climate and where the climate is more sub-tropical green manure will probably have more lasting effects as has been shown by the few trials made in the more northerly parts of Nigeria.

3. Complete removal of the above-ground parts of the green manure crop reduces, but is far from wholly preventing, the benefit that results in the crop that follows a leguminous one. This result could explain in part the significant yield increases obtained from the pigeon pea fallow in the No. 1 Rotation Experiment at Lilongwe, where the above-ground parts were burned rather than removed from the plots, even though it has only been applied in this case to the following crop.

Many of the results above have been confirmed by later work (Doyne, 1937) and it may be generally said that they do not depend closely on the type of soil used provided only that the land is capable of growing the green manure crop. The results of green manuring on the highly-acid soils of south-eastern Nigeria have been disappointing but the failure has always been explicable by the fact that the green manure crop itself was a failure. Very similar results were obtained when experiments similar to those above were repeated at Ilorin where the soil, though different from that at Ibadan, grows legumes well.

In Kenya, a considerable amount of experimental work was done over a period of years on green manuring in the European Highlands both in the Rongai-Njora area (altitude 7,000 ft., rainfall 30 in. to 35 in.) and in the Trans-Nzoia (altitude 6,000 ft., rainfall 40 in. to 45 in.) (Webster, 1954). In the former area green manuring was ineffective and this was attributed to the relatively low rainfall, although whether this resulted in poorer growth of the legume or slower decomposition of the green manure because of reduced activity of micro-organisms under low rainfall conditions or poorer nodulation of the legume is not stated. Nevertheless the statement does not agree with the conclusions reached at Ibadan where it was considered that green manuring would probably have more lasting effects in a more sub-tropical climate.

Further experiments in the Rongai area have since been conducted and a trial to determine the effect of interplanting legume on maize yields was laid down on three farms (Reid, 1956). No details of the legume used, spacings or cultural treatment are given but the results obtained were as follows :

Farm A—Altitude 6,000 *ft.*—Plots without interplanted legume yielded better than those with the legume but the differences were not significant. This was in a year when growth was good and farm yields in the district were good.

Farm B—Altitude 5,900 *ft.*—Plots with interplanted legume yielded slightly better than those without legume but the differences were not significant.

Farm C—Altitude 7,900 *ft.*—Plots without interplanted legume gave significantly higher yields, at the five per cent. level, than plots with interplanted legume.

In these trials, where the legumes were grown in conjunction with the maize crop and were not used as a green manure preceding the crop, no great response to the legumes could be expected although following crops could show increased yields after decomposition of the plant material and release of mineral nutrients.

The experiments referred to previously in the Trans-Nzoia area, showed that green manuring produced appreciable yield increases in the following maize plots as compared with plots which grew maize continuously but the effect

did not persist beyond the first crop following a season's green manuring and the practice of growing green manure and maize in alternate seasons did not appear to be economic.

Finally, mention should be made of a few experiments in which green manures have been used prior to a swamp rice crop. At the Mahiwa Experimental Station in Tanganyika the following rotations were tested (Clegg, 1953-1954).

R.1 Kudzu, Kudzu, Rice, Rice, Rice

R.2 Rice, Rice, Rice, Rice, Rice

R.3 Cassia loppings plus Rice continued

R.4 Sweet potato and Rice continued

The cassia loppings were puddled into the plots prior to planting the rice crop. In the first year, R3 gave significantly higher yields than R2 at the five per cent. level but in the second year there was no signifiant difference between treatments. Results beyond the second year have not been published.

Experiments in some of the principal rice-growing tracts of India have proved that the interval between the first monsoon showers and the transplanting of rice seedlings can be profitably used for the growth of a cover crop as a green manure (Dobbs, 1916). Under favourable conditions the seed of the cover crop may even be sown at the end of the preceding cold weather and the young crop will survive the hot weather and be ready to take full advantage of the early part of the monsoon. Some typical results from such experiments are as follows :

1. Rice as first crop—yield 924 lbs. padi/acre
   Sesbania aculeata as a cover crop—ploughed in after four months
   Rice yield 2,086 lbs. padi/acre
2. Rice as first crop—yield 904 lbs. padi/acre
   Crotalaria juncea as a cover crop—ploughed in after two months
   Rice yield 1,584 lbs. padi/acre
3. In Bombay, rice yields were increased by 660 lbs. per acre by sowing *Crotalaria juncea* immediately after a rice crop and ploughing in at the time of flowering.

PLATE 6.—*Preparatory cultivation for a rice crop in Trinidad.*

A Survey of Results from Long-term Rotation Trials

As with shorter rotations in areas with an annual rainfall above 60 in., long-term rotation trials conducted under similar conditions have indicated that leguminous cover crops used as green manures fail to maintain soil fertility as measured by crop yields. Even so the evidence from the two trials to be described is not of sufficient value to allow outright condemnation of the use of cover crops in these areas.

Firstly, in Ghana, a rotation trial was begun in the mid-1920s at Ejura, near Kumasi, an area which is situated in open savannah country just outside the forest zone and subject to the rather severe "harmattan", but which has a rainfall of 60 in. per annum falling mainly in a long rainy season from mid-April to mid-July and a short rainy season in September and October. The object of the trial was to study continuous cultivation in comparison with a crop rotation having fallow periods every alternate year as shown in Table IX (Waters, 1929).

TABLE IX

Rotation Trial—Ejura

Rotation	A_1	A_2	B_1	B_2	C_1	C_2
1924	Groundnut	Groundnut	Yam	Fallow	Cereal	Cereal
1925	Yam	Fallow	Cereal *	Cereal *	Groundnut	Fallow
1926	Cereal *	Cereal *	Groundnut	Fallow	Yam *	Yam *
1927	Groundnut	Fallow	Yam *	Yam *	Cereal	Fallow
1928	Yam *	Yam *	Cereal	Fallow	Groundnut *	Groundnut *
1929	Cereal	Fallow	Groundnut *	Groundnut *	Yam	Fallow

For the continuous rotations A_1, B_1 and C_1 there is a three year rotation of groundnut cereal and yam and for the alternate fallowing rotations A_2, B_2 and C_2 the same crops are grown over a period of six years. During the fallow period, cover crops, usually *Mucuna* sp. were grown on the land. Maize was the cereal used.

Comparisons between the yields of those crops marked with an asterisk in Table IX showed that in five out of seven cases, yields from the "continuous" rotations were greater than yields from the "fallow" rotations despite the fact that the cropping rate was twice as heavy in the "continuous" rotations.

During the trial *Imperata cylindrica* increased on the fallow plots to the extent that the cover crops planted during the fallow period were unable to keep this grass in check. Therefore they were not fully effective as cover crops so that comparisons between yield figures are possibly not truly indicative. Also the statistical significance of yield differences are not given, but comparisons within pairs show that the lower yield in four pairs is over 90 per cent. of the higher yield and the conclusion from the trial that the system of cover crop fallows was not a success should be viewed in the light of the above facts. The point is however, that the "fallow" rotations certainly resulted in no startling improvement in yields over continuous cropping.

Previously it was shown that in Nigeria late-grown green manures appeared to be highly successful in Ibadan (rainfall 48.5 in.) and also at Ilorin (rainfall 51.4 in.), but in higher rainfall areas such as Umuahia and Benin it has yet to be proved that continuous cultivation is feasible under a green manuring system (Lewin, 1931). For example, at Umuahia where annual rainfall is 99.62 in. a block which was cropped annually with early maize and late cover crop of *Mucuna* steadily declined in productivity over a period of five years as shown.

	Maize Yield
Year 1	1,102 lb.
2	1,154 lb.
3	650 lb.
4	459 lb.
5	376 lb.

pH of the soil cropped was between 5.3 and 6.0 and apparently the block was exposed for

some time between the harvest of maize and establishment of the leguminous cover so that a certain amount of leaching of mineral nutrients must have occurred during this period. The rotation can be considered as fairly intensive and it is possible that if the period of cover cropping were extended for at least one year and preferably longer the yields may have been maintained at their original level, as in the trial described below at Ilorin. Actually, later work at Umuahia did reveal that as an early sown whole season crop, *Calopogonium* formed a good cover, except on the very poorest soils, from March to December and unlike *Mucuna* was little affected by soil acidity (Buckley, 1938). It has also been stated that *Calopogonium* is capable of maintaining fertility of the soil under continuous cropping provided that :

(*a*) The soil is in " good heart " when continuous cropping is begun

(*b*) The soil is never allowed to lie bare and exposed to wash after continuous cropping has begun.

In the trial at Ilorin, a three year rotation based largely on local practice with regard to choice of economic crops, was commenced on three separate ten acre blocks in 1923 (Lewin, 1931). The station has an altitude of 920 ft. and average annual rainfall of 51.4 in., with the wet season falling between April and October. Soils are sandy with ironstone concretions and slightly acid to neutral (pH 6.4-7.0).

The rotation was :

Year 1 Maize sown in April and interplanted with guinea corn in May. Maize harvested in August. Yams interplanted in guinea corn in November.

Year 2 Yams interplanted with cotton in July. Harvested October-November.

Year 3 *Mucuna* sown and turned under twelve months later.

The yields are shown in Table X.

TABLE X

Ilorin Three year Rotation—Yields in lbs./acre

——	Year	Yams	Cotton	Year	Maize	Guinea Corn
Block A.1-20	1923	10,155	66 (Allen)	1925	1,709	....
	1926	14,203	166 (Native)	1928	649	633
	1929	10,685	136 (Native)			
Block A.21-40	1924	5,510	75 (Allen)	1923	856	314
	1927	8,502	124 (Native)	1926	1,386	710
				1929	1,479	767
Block A.41-60	1925	10,214	74 (Native)	1924	1,177	442
	1928	9,903	185 (Native)	1927	1,340	632

During the experiment, yams were capped with a thick layer of grass to protect them from excessive heat at the time of sprouting as is the local practice. A considerable quantity of organic matter was thus added to the plots and this could contribute to the maintenance of fertility. However this form of mixed cropping combined with a twelve month cover of *Mucuna* appears to have allowed adequate maintenance of yields although no statistical consideration of the results has been made.

Elsewhere in Nigeria, under similar conditions to those existing at Ilorin, rotations based on mixed cropping with a one year cover crop appear to have been satisfactory. Two such rotations were commenced at the Yandey Agricultural Station which has an annual rainfall of 54 in. and wet season from April to October as at Ilorin (Briggs, 1938). These rotations are shown in Table XI.

TABLE XI

Mixed cropping rotations—Yandey.

—	Rotation I	Rotation II
Year 1	Yams and intercrops	Yams and intercrops
Year 2	Millet and Guinea Corn	Benneseed followed by *Mucuna*
Year 3	Benneseed followed by *Mucuna*	Millet and Guinea Corn
Year 4	*Mucuna*	*Mucuna*

Although no yield figures are given in the report of this trial it was indicated that up to the third cycle both rotations appeared to be satisfactory for maintenance of yields.

One of the most detailed and well replicated trials to be found in the literature is that begun several years ago at Serere in Uganda and still in progress. As a result of earlier work at Serere in which it was shown that a green manure crop grown in the early rains failed for five successive years to improve the yield of cotton grown in the late rains and, in general, experiments aimed at maintaining fertility with green manure crops were unsuccessful, the "Fertility Experiment" as it is called, was designed to find a solution to the following problems for conditions in Uganda (Martin and Biggs, 1936-1937, Parsons, 1954).

1. The minimum period of rest necessary to maintain fertility
2. The best type of cover during rest
3. The dosage of animal manure necessary in conjunction with the above

The station has an annual rainfall of 53 in., is 1 degree 30 minutes north of the equator and has a light loamy soil with a pH a little over 6.0. Three basic rotations, comparing fallow periods of one, two and three years were used as shown in Table XII.

To these three basic rotations, the following five different resting covers were applied so that in effect fifteen different rotations were compiled in which comparisons were made between four rest crops and natural regeneration for periods of one, two and three years.

1. Natural regeneration : This in effect was a more or less pure stand of *Imperata cylindrica.*

PLATE 7.—*Yam cultivation near Wale Wale, in Ghana.*

TABLE XII

The Basic Rotations, Serere

Year	Rotation 1	Rotation 2	Rotation 3
1. Spring	Preparation of land	Preparation of land	Preparation of land
Autumn	Cotton	Cotton	Cotton
2. Spring	Eleusine	Eleusine	Eleusine
Autumn	Cotton	Cotton	Cotton
3. Spring	Groundnuts	Groundnuts	
Autumn	Sweet potatoes	Sweet Potatoes	REST
4. Spring		Sorghum	
Autumn	REST	Cotton	REST
5. Spring			
Autumn	REST	REST	REST

2. Planted grass : *Cynodon* sp. was planted and allowed to compete with natural grass. Some *Cynodon* persisted but the dominant constituent of this fallow was *Imperata cylindrica.*
3. Planted grass slashed : *Cynodon* persisted rather better than in the above fallow but *Imperata cylindrica* was normally dominant In the second circuit of the experiment slashing was replaced by grazing.
4. Green manure slashed : *Mucuna nivea* was used and the plots dug-over and re-sown once a year during the fallow period. In most cases the *Mucuna* stand was fairly good though occasional invasion of plots by *Imperata cylindrica* occurred.
5. Green manure dug in : *Mucuna nivea* was used, plots being dug over and re-seeded twice yearly.

To the fifteen rotations three levels of manuring with farmyard manure were applied as split plot treatments resulting therefore in a total of forty-five different rotations. All rotations were then replicated twice in space and five times in time with the result that the final design consisted of four hundred and fifty plots. For the replications in time, ninety new plots were brought into cropping each year for the first five years. The results at the conclusion of three five-year circuits of this trial can be summarised as follows :

1. Two years rest under ungrazed natural regeneration will maintain fertility.
2. Three years rest under grass ley, grazed or ungrazed will maintain fertility.
3. Green manuring is as effective as grass ley.
4. Five tons of farmyard manure applied once in five years will maintain fertility.

A series of experiments conducted for many years at Ibadan in Nigeria have been similarly well replicated and the results from these are of considerable interest and value, particularly as the area is representative of a large part of the Western Provinces of Nigeria and an even larger area of very similar topography climate and soils in Ghana, covered by the " Dry Forest Zone " and the northern part of the " Rain Forest Zone ". As previously mentioned the annual rainfall of 48.5 in. falls mainly in the months from April to November with two intense periods of rain in May-June and September-October and a break in the rains in August. Loose brownish topsoils overlie porous reddish to yellowish sand or sandy clay subsoils, the profiles generally having very free internal drainage. The topsoil is naturally weakly acid to neutral, the quantity of bases set free from decomposition of leaf litter being almost or quite sufficient to saturate the base-exchange capacity of the colloids of the surface layer (Vine, 1953).

One of the earliest rotation experiments at Ibadan, the " 1922-1933 Main Rotation " tested the following sequence of cropping :

1st Year	2nd Year	3rd Year	4th Year
Early Maize	Yams	Mucuna	Groundnuts
Mucuna	Mucuna	Cotton	Mucuna

During the twelve years the trial was in progress, no appreciable decline in yields was shown, this result being more striking in view of the fact that there was a continuous succession of good seasons for early maize from 1922 to 1932. It is significant however that despite the fact that yields were adequately maintained the local farmers object to the work entailed in digging in the bulky green material to which the maintenance of yield levels was attributed.

In a number of other experiments continuous rotational cropping using no manure other than leguminous green manure was tested. Generally these showed a definite but only gradual diminution in crop yields. For example, seven plots continuously cropped from 1932 to 1951 with maize and *Mucuna* (slashed, burnt and ashes dug in) gave the following average yields of grain :

Average 1932-1937	....	1,360 lbs. per acre
Average 1938-1941	....	1,540 lbs. per acre
Average 1942-1945	....	1,420 lbs. per acre
Average 1946-1949	....	1,460 lbs. per acre

Yields of the same variety of maize on these plots, under similar cropping, were about 2,000 lbs. per acre in an earlier experiment which lasted from 1926 to 1930.

Another experiment was started in 1923 on twenty acres of land, newly cleared from secondary bush, comparing five rotations having different proportions of green manure crops to other crops and thus varying from light to heavy cropping intensities as shown in Table XIII.

All rotations were replicated twice in space and four times in time on plots each one-half acre in area as shown in Table XIV.

TABLE XIII

Five 4-Course Rotations—Ibadan

——	1st Course	2nd Course	3rd Course	4th Course
Rotation I	*Mucuna*	*Mucuna*	Groundnuts	Yams
	Cotton	Late Maize	*Mucuna*	*Mucuna*
Rotation II	*Mucuna*	Early Maize	Groundnuts	Yams
	Cotton	*Mucuna*	*Mucuna*	*Mucuna*
Rotation III	*Mucuna*	Groundnuts	Early Maize	Yams
	Cotton	*Mucuna*	Late Maize	*Mucuna*
Rotation IV	Groundnuts	Early Maize	Groundnuts	Yams
	Cotton	Late Maize	*Mucuna*	*Mucuna*
Rotation V	Groundnuts	Early Maize	Early Maize	Yams
	Cotton	Cowpeas	Late Maize	*Mucuna*

TABLE XIV

Five 4-Course Rotations—Ibadan

BLOCK I 1st Course	Five rotations replicated twice	Continued for 8 years
BLOCK II 2nd Course	Five rotations replicated twice	Continued for 11 years
BLOCK III 3rd Course	Five rotations replicated twice	Continued for 18 years
BLOCK IV 4th Course	Five rotations replicated twice	Continued for 9 years

Rotations were continued in the blocks for the varying periods shown in the right hand column. For the first one to eight years, yields were fully maintained in all rotations with very little beneficial effect from green manuring apparent, that is the yields of maize and cotton after digging-in *Mucuna* were not much greater than those after scraping up the soil on old ridges after another crop (groundnuts, maize or cotton). The differences could have been entirely due to the effect of digging of the soil when *Mucuna* was incorporated. However valid this explanation that yield differences resulted from variations in cultural treatments might be, it is apparent that in this experiment on land newly cleared from secondary forest nitrate was not limiting

in the first ten years and it is possible that under the careful management applied to the trial that the gradual decomposition of humus reserves in the newly cleared soil were sufficient to provide an adequate supply of nitrate for this period.

The five above rotations were continued, in Block III only, for 18 years as shown in the Field Plan but the yields of early maize and late maize declined markedly in Rotation V, the most intense rotation. Yields of late maize also declined in Rotation III where the crop was not immediately preceded by a green manure. A similar result was obtained with a new rotation applied to Block I, that is where the rotation was fairly intensive and hence the number of green manure crops reduced, yields eventually declined seriously. This contrast to the earlier years of cropping strongly suggested that the level of nitrate which was earlier provided through decomposition of accumulated humus had decreased considerably and the reduced number of green manure crops in the more intensive rotations was inadequate for maintenance of the earlier nitrate levels in the soil. That the yields may have been maintained by green manure had the intensity of cropping been fairly light was shown by certain other experiments conducted on land which had been cropped for some years previously. These compared two or more rotations in which the proportion of green manure crops to other crops varied as the position of the green manure crops in the rotation differed and it was found that yield of maize after green manure was about 550 lbs. per acre more than that of maize after another crop (maize or cotton). The difference was ascribed to an increase in the nitrate supply after green manure. In fact soil nitrate determinations showed that incorporation of *Mucuna* was rapidly followed by a large increase in nitrate content.

The decline in yields in the above rotations does suggest the possibility, under Ibadan conditions, of returning the land to a bush fallow after approximately eight years of rotational cropping as suggested by Tondeur (1955). This may of course necessitate the introduction to the area of viable seeds of tree species or the use of a planted tree fallow.

The " 1922-1933 Main Rotation " mentioned earlier was converted in 1933 into the following rotation :

Slashing and burning of the legume was introduced for those popondo crops (*Phaseolus lunatus* var.) marked with an asterisk. Otherwise the legumes were dug in.

1934-1945 Main Rotation—Ibadan

Year 1	Year 2	Year 3	Year 4
Early Maize	Yams	Early Maize	Early Maize + *mucuna*
Popondo	Popondo *	Cotton	Late Maize + Popondo

By 1944 it was apparent that poor yields were being obtained consistently from this rotation which was more intensive than the original Main Rotation by which yields had been maintained for twelve years. However the result agrees closely with those obtained when the five four-course rotations were continued for eighteen years and the reason for this decline in yields was clearly demonstrated in 1945 when a factorial fertiliser trial with N, P and K was applied to the 1933-1945 Main Rotation plots. This clearly showed that the main and possibly only important factor was lack of nitrogen.

The experiments have demonstrated that yields obtainable from Ibadan soils can be maintained at a reasonable level for considerable periods of cultivation without the use of fertilisers provided that the rotations applied include a green manure crop once every year or at the least once every two years. Fertility declines if cultivation is prolonged for more than eight to ten years. On land which has previously been rather intensively cropped for some years *Mucuna* will induce a yield response in the crop following it. The beneficial effect stems from the rapid production of nitrate following incorporation of the leguminous green manure but it does not produce any lasting increase in the levels of humus in the soil which will decline.

It is therefore obvious that for the large areas in Nigeria and Ghana with similar climate and soils to those at Ibadan land could be cropped after clearing for eight to ten years, using rotations similar to those described above, and then either returned to bush fallow, dressed with fertiliser or possibly rested under a perennial legume fallow. In this respect trials in progress at Ibadan have indicated that good pastures of *Centrosema pubescens* mixed with certain grasses (notably *Cenchrus ciliaris*) can be established

and alternated with a period of rotational cropping without allowing the diminuition in humus content that occurs under continuous cropping.

Two trials at Ukiriguru in Tanganyika are of interest in this section because of the relationship between their results and those obtained at Serere with regard to the efficiency of natural regeneration or "tumbledown" fallow as a fallow cover in rotational cropping. The rainfall at Ukiriguru (39.42 in. per annum) is lower than that at Serere and soils are described as "hill sands".

The first trial, Trial 5, was designed as a resting crop trial to test the value of the following seven treatments used as resting crops for a three-year period prior to cropping with bulrush millet and cotton as indicator crops (Anon, 1953-1956).

1. Annual cropping—residues carried off
2. Annual cropping—residues grazed
3. Cassava—weeded the first year only
4. Tumbledown fallow—grazed
5. Planted grass fallow—not grazed
6. Planted grass fallow—grazed
7. Planted grass fallow undersown with *Tephrosia* and *Crotalaria* and grazed.

Treatments were applied for three years before the indicator crops were planted and these were rotated on the plots so that in any season half the replicated plots for each treatment were cropped with cotton and half with bulrush millet.

The second trial, Trial 7, was similarly designed as a resting crop trial but with dressings of organic and inorganic manures included and tested the value of the following eight treatments by cropping with bulrush millet and cotton as indicator crops after five years (Anon, 1953-1956).

1. Annual cropping—no manure
2. Annual cropping + soda phosphate at 600 lbs. per acre in the 1st and 2nd year + double superphosphate at 200 lbs. per acre in the 5th year
3. Annual cropping + FYM at 7½ tons per acre in the 1st and 2nd year + compost at 6 tons per acre in the 5th year
4. Tumbledown fallow—grazed
5. Tumbledown fallow—not grazed
6. Planted grass fallow—grazed
7. Planted grass fallow undersown with *Tephrosia* and *Crotalaria* and grazed
8. Planted grass fallow undersown with local creeping legumes and grazed.

Yields from the first and second indicator crops in Trial 5 and the first, second and third indicator crops in Trial 7 showed that, although the grazed tumbledown fallow and grazed planted grass fallow undersown with *Tephrosia* and *Crotalaria* were significantly better than continuous cropping treatments, there was practically no difference between the cotton and millet yields from either of these two treatments. However in Trial 5, the third indicator crop yields revealed that the response to the grazed planted grass fallow with legumes had ceased while grazed tumbledown fallow gave a yield increase with cotton only. In Trial 7 the fourth indicator crop yields showed that response to the grazed tumbledown fallow was no longer evident while the grazed planted grass fallow with legumes gave a yield increase with millet only. Therefore the three and five year fallows of the two treatments under discussion were really only effective in producing significantly higher millet and cotton yields for two and three cropping periods respectively and neither fallow proved superior to the other.

SECTION IV

Summary and Discussion

The traditional system of subsistence agriculture throughout the tropics is mainly based on shifting cultivation or bush fallow rotation, the latter system being more general. With this method of farming, land is cleared, usually burnt, cropped for two or three years and allowed to revert to a natural vegetation cover for a period, which may vary from three to fifteen years, before being cropped again. The length of the fallow period is mainly dependent on population pressure. Experiment has shown that fallow re-growth can be considerably improved if, when clearing, trees and bushes are cut off at ground level rather than two or three feet above ground level as is the more usual practice and if cuttings are heaped up for burning between roots rather than on top.

The commonly-assumed fact that clearing and burning *in situ* with incorporation of the ash, will lead to higher crop yields has been proven and it is this stage of the bush fallow rotation, between clearing the forest and cropping, which is the most critical period, particularly if the felled bush is burnt. On clearing, considerable quantities of organic matter are added to the

soil from which are liberated large quantities of mineral nutrients as a result of microbial decomposition or burning. Therefore substantial mineral nutrient loss can occur, before the cultivated crop is sufficiently developed to re-immobilize most of the nutrients, through leaching, run-off and percolation. This loss is reduced if the first crop is planted and grown concurrently with decomposition and disintegration of the trash and if the trash is not burnt. However, during the two or three year cropping period, organic humus reserves in the soil and the mineral fertility linked to this reserve may be depleted or weed infestation may become too intense and consequently a short cultivation period has to be followed by a bush fallow period to allow restoration of fertility and the local climax vegetation.

At the commencement of the fallow period after cropping, nutrient immobilization by a tropical rain-forest fallow has been shown to be rapid. Within five years the total quantity of nutrients immobilized is more than half the total immobilized in an eighteen-year-old forest fallow. Leaf growth rapidly approaches a maximum and later increases in the total growth of the fallow occur chiefly in the woody parts. Also within five years root growth reaches about 75 per cent. of the total root growth after eighteen years. The most important factor in nutrient immobilization, particularly uptake and release of nitrogen, is the tree leaf. Litter accumulation reaches a maximum in eight to twelve years and decomposition of plant material on the forest floor is more rapid than in temperate zone forests as a result of a combination of high temperature and humidity and greater insect and micro-organism population. The rate of loss of the main nutrients during decomposition is variable so that a balanced nutrient supply for crop plants may not be provided by the forest fallow.

The main advantages of the bush fallow are that it :

1. Requires neither planting nor management.
2. Provides a break in the cropping which helps to control plant pests and diseases and weeds.
3. Improves soil structure by virtue of both rest from cultivation and biological activity.
4. Prevents erosion to a variable degree.
5. Provides a cover which protects the soil from sun and rain and thereby reduces the rate of disintegration of organic and inorganic crumbs and leaching of mineral nutrients.
6. Is composed of deep-rooted bush trees which withdraw nutrients from the lower soil horizons and return them to the surface in organic combinations thereby preventing their loss by virtue of immobilization.

The main disadvantages of the bush fallow are :

1. Increases in population pressure on a given area of land lead to extension and intensification of the cropping period, a reduction in the fallow period and thus the failure of the bush fallow to maintain soil fertility.
2. This failure results from the fact that the effective regeneration of the natural vegetation is reduced and the tree species under conditions of repeated cutting do not become re-established. In the absence of competition from the natural vegetation for soil nutrients, water and light, annual plant species, consisting mostly of grasses, invade the fallow. Once established, grass species are able to rapidly dominate the fallow, particularly if assisted by fires which become more prevalent as grasses are established and destroy the above ground growth of regenerating or seedling trees. In the absence of a tree cover, withdrawal of mineral nutrients from the lower soil horizons and their return in organic combinations to the surface layers ceases and decomposition of soil organic matter and leaching of mineral nutrients increases in intensity. The land becomes more vulnerable to sheet and gully erosion.
3. The bush fallow rotation system is grossly uneconomic in terms of land and labour and does not allow for an increase in agricultural production.
4. Where periodic movement of villages occurs in association with the pursuance of an agriculture based on this rotation, accumulation of material wealth and professional differentiation and specialization are not encouraged. Education and health tend to suffer.

Investigations into the optimum length of bush fallow are in progress at Aiyinasi in Ghana and the Belgian Congo where a fallow period of twelve years is at present recommended and

used under Government supervision. In Southern Nigeria, a Rosaceous tree *Acioa barteri,* is planted as a fallow crop and is in fact almost the only satisfactory fallow cover which can be established on the leached, impoverished acid soils in this region. It has been shown to have an equal if not greater regenerating value than a bush fallow. In the highlands of New Guinea *Casuarina* trees are grown in the fallow period and in Sierra Leone the forest tree *Gmelina arborea* shows promise for use as a planted fallow.

With the realization that the bush fallow could only maintain fertility for subsistence agriculture in sparsely populated areas, investigations were initiated to ascertain whether it could be replaced by rotations combining food crops with leguminous cover crops and green manures. This approach stemmed from the accumulated evidence in temperate climates pointing to the beneficial results obtainable from the use of legumes in rotations. In the early part of this century authors listed many advantages which could be derived by using cover crops and green manures in the tropics, but it is now generally considered that the main point in relation to this practice is that, while it can result in an increase in the organic matter content of the soil or an increase in the available nitrogen in the soil, it will not confer both benefits simultaneously and may confer neither. In this respect it has been shown that the addition of a green manure to the soil may so stimulate the activity of the soil micro-organisms that they not only attack the material added but also some of the more-resistant organic matter. If the subsequent crop does not become sufficiently developed to take up the nitrate soon after it is released it may well be lost by leaching, as a high correlation exists between leaching of nitrate nitrogen and rainfall. Cover crops and green manures may also reduce losses of mineral nutrients by leaching, increase the concentration of mineral nutrients in the surface soil, prevent erosion, protect the soil from rain and sun and successfully compete with weeds. However, several fundamental points in relation to the functioning of legumes, such as the degree of nodulation that occurs and the efficiency of nodule bacteria in fixing nitrogen, require further investigation in tropical areas.

Both long- and short-term rotation trials in areas which have an annual rainfall greater than 60 in. and a natural climax vegetation of tropical rain-forest have failed to maintain yields or give greater yields than continuous cropping. Rapid breakdown of organic matter under conditions of high temperature and humidity coupled with rapid loss of nitrate nitrogen and other mineral nutrients has been nominated as the cause of this failure. There are, however, indications that in some of the trials certain modifications may have resulted in a better response to the leguminous cover crops and the possibility of using legumes in crop rotations in higher rainfall areas cannot be disregarded without further experimental evidence.

In certain areas where the annual rainfall lies between 30 in. and 60 in. and falls mainly in either one long wet season or one long and one short wet season, legumes used in short-term rotation trials have in most cases increased the yields of the crops following, when compared with a continuous cropping system involving one or more crops. A two-year leguminous cover usually results in better yields than a one-year leguminous cover. It has been shown that a yield increase following a leguminous cover crop grown for one season may be due merely to the function of the legume as a different crop to the one following rather than to its function as a legume. Interplanting of legumes with a cereal crop has not increased yields of the concurrent crop but the experiments have not been of sufficient duration to provide any estimate of the effect that interplanted legumes may have on subsequent crop yields. However, mixed and rotational cropping in long term rotations have allowed maintenance of yields for periods of up to eight years. Various treatments of the cover crop have shown that yields from a crop immediately following do not differ significantly whether the cover crop is cut at flowering and either dried and burnt or dug in, or allowed to mature and either dried and burnt or dug in. Complete removal of the above-ground parts of a green manure reduces but does not wholly prevent a yield increase in the following crop.

The fact that a leguminous fallow may be no more effective than natural regeneration or tumbledown fallow has been demonstrated in both long- and short-term rotation trials. In the No. 2 Rotation Experiment at Lilongwe a rotation based on alternate years of cropping and natural regeneration was as effective as a rotation based on a two-year legume fallow

alternating with two years of cropping. A three-year rest under *Mucuna* used as a green manure has been shown at Serere to maintain fertility in a five-year rotation but a two-year rest under natural regeneration was as effective in a similar rotation. In addition the Ukiriguru trials proved a tumbledown fallow to be as effective as a planted grass fallow undersown with legumes, both fallow in this case being grazed. Unfortunately similar comparisons have not been made in rotation trials at Ibadan. In a series of other experiments at this Station it has been shown that yields can be maintained for eight to ten years of cultivation without the use of fertilisers provided that the rotations applied include a green manure crop once every year or at least once every two years, the green manure apparently only acting as a "booster" which helps to maintain levels of soil organic matter and nitrate nitrogen which are largely derived from the humus present in newly-cleared land. Fertility eventually declines if cultivation is prolonged for more than eight to ten years. For the large areas of Ghana and Nigeria with similar climate and soils to those at Ibadan, land could therefore be cropped for approximately ten years after clearing from secondary bush, using rotations similar to those at Ibadan and then either :

(*a*) Returned to bush fallow and rested for several years

(*b*) Rested under a perennial legume or grass-legume fallow

(*c*) Cropped for further periods with the use of inorganic fertilisers, particularly sulphate of ammonia, where these are available and economical to use.

Consideration of all these rotation trials, particularly the more comprehensive long-term experiments, reveals that if rotational cropping with foodcrops and legumes is to be used, the cropping intensity must be light if fertility is to be maintained for any length of time. In fifteen years of cropping at Serere with a rotation based on *Mucuna* as the legume, cotton as a cash crop and *Eleusine* as a foodcrop, only six cotton crops and three *Eleusine* crops could be grown without loss of fertility. Where the legume was replaced by a natural regeneration fallow, three groundnut crops and three sweet potato crops could be grown in addition to the cotton and *Eleusine*. Three and five year tumbledown fallows or planted grass fallows undersown with legumes were only effective at Ukiriguru in producing significantly higher millet and cotton yields in the following two or three cropping seasons respectively. These results together with those from Ibadan suggest that where rotational cropping using legumes as a fallow has been successful in maintaining yields it has probably been no more economic in terms of land and management than the bush fallow. It is suggested that the possibility of fairly intensive cropping for a few years even without the inclusion of legumes, followed by fallow periods of several years should be considered for those areas where fertility has not declined to the extent that such a system is not feasible.

The survey of the literature has shown that in African areas and elsewhere there has been so little work done on the above problems of fertility maintenance in subsistence agriculture and the results have been so variable that it is quite impossible to come to any general conclusions for the widely divergent climatic and soil conditions which exist where subsistence agriculture is practised. The points listed below are intended only as suggestions for consideration in any further experimental work on this problem and on this problem only, that is the production of food by rotational cropping as it has been considered in this literature survey. The use of those alternative systems of farming listed previously and the use of farmyard manures, compost and so on are not considered in these recommendations, but should and must be considered in relation to the problem as a whole.

1. In tropical rain-forest and other high-rainfall regions where ample land is available for cultivation the bush fallow rotation will maintain fertility as effectively as any other system of agriculture. Any trials which are conducted should be designed to investigate :

(*a*) The possibility of replacing or combining with the bush fallow a planted tree fallow using either indigenous forest species or vigorously-growing leguminous trees such as *Gliricidia* and *Leucaena* species. These should be carefully investigated for the occurrence and effectiveness of nodulation. When clearing for cultivation, trees may be either lopped and crops grown between rows or stumped and crops grown over the whole area.

(*b*) Modification of the bush fallow to a system such as the "Corridor" system in the Belgian Congo, which will lead to

stabilization of the community with its attendant benefits and probably greater and more economic production of food.

(*c*) Comparison between bush fallow and a perennial, creeping, legume fallow with appropriate consideration of the vigour, depth of rooting and nodulation of the legume used.

2. In tropical rain-forest and other high-rainfall areas where population density is high and a land shortage exists, one of the first lines of approach should be an investigation into the availability of inorganic fertilisers, existing mineral deficiencies, the economics of fertiliser application and the problems presented in persuading the peasant farmer to use fertilisers. Crop yields and net farm incomes in the Belgian Congo have been increased considerably through the use of commercial fertilisers and by ploughing in a cover crop such as velvet bean, *Mucuna* or *Crotalaria*.

3. In lower rainfall areas (30in. to 60in. per annum) where a serious decline in fertility has occurred as a result of high population pressure and the main problem to be faced is in the establishment of any type of fallow cover, investigation should be based on :

(*a*) The establishment of a leguminous cover crop, a leguminous tree crop or any other kind of tree crop either foreign or indigenous

(*b*) The practicability of using fertilisers on the impoverished soils either to increase foodcrop yields or for the establishment of a fallow tree crop or both.

4. In the lower rainfall areas where the soil is reasonably fertile and population pressure and land availability are variable, consideration should be initially given to some of the results from rotation trails surveyed in preceding sections and trials should cover some of the following points as considered necessary in the light of existing information available. Such trials should be conducted on land which is preferably neither highly fertile nor exhausted by continuous cropping, but which is representative of the majority

PLATE 8.—*A permanent system of agriculture in St. Vincent in the West Indies. Contour [illegible] of mountain side crops.*

of the foodcrop production areas in the district.

(*a*) Comparison between the effectiveness of natural regeneration or tumbledown fallow, planted tree fallow and leguminous fallow in maintaining fertility.

(*b*) Testing of various legumes for vigour of growth, seed production, effectiveness of nodulation, depth of rooting and persistence during dry seasons.

(*c*) Companison between intensive cropping for a short period without the use of legumes and light cropping rotations with the inclusion of leguminous covers for longer periods, both with respect to maintenance of fertility and economy of production.

(*d*) The practicability of using inorganic fertilisers with the attendant associated investigations of mineral deficiences, economy of use and availability.

(*e*) Comparison between the various possible treatments of a fallow cover prior to cropping for example burning or digging in at flowering or maturity.

(*f*) Comparison between rotations in which legumes are interplanted more or less regularly with the foodcrops or cash crops and rotations in which the foodcrops and cash crops are alternated and included with these, treatments to test the effectiveness of burning both cover crop and crop refuse against digging them into the soil.

In conclusion, the over-riding importance of the problem of changing the system of agriculture of any peasant farmer must be stressed. In the past it has been found virtually impossible to persuade the African farmer to grow a cover crop which he will merely dig in without harvesting anything from it. Even so, where an agriculture based on rotational cropping with legumes is proved to be effective and where there is no other alternative, some attempt must be made to introduce the use of legumes, and in this respect it should be remembered that there are legumes which produce edible pods, burning a cover crop is probably as effective as digging it in and interplanting legumes with foodcrops is probably as effective as alternating a legume with foodcrops.

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THE ROOT-KNOT NEMATODE

BY L. B. THROWER *

Nematodes, or eelworms, are a group of semi-microscopic animals, some of which are parasitic on plants or other animals, others may be free-living. The eelworms which are parasitic on plants may be either sedentary or migratory, the latter group including those that are active within the roots of the host as well as those that feed upon the outer tissues. Root-knot nematodes are sedentary and spend the greater part of their life cycle within the tissue of the host. Until recently, these nematodes were thought to belong to a single species, *Heterodera marioni,* but they are now considered to belong to the genus *Meloidogyne,* of which several species have been described.

Although the root-knot eelworm has a distribution extending from temperate to tropical climates, it is particularly favoured by the warmer climate of the tropics where the absence of a cold season permits ten or more generations to be passed in twelve months.

Since the roots are the only parts to be directly affected, damage caused by *Meloidogyne* spp. is often overlooked during the early stages of the disease.

Hosts of the root-knot nematode

More than 1,500 species of plants have been recorded as hosts of the root-knot nematode throughout the world. The table lists some of the plants, grown in the Territory, which are susceptible to root-knot. Those marked with an asterisk have been recorded as hosts of the root-knot nematode in Papua and New Guinea.

TABLE 1.—Plants Susceptible to Root-knot

Vegetables	Ornamentals	Commercial crops
* Beetroot	* Dahlia	Banana
* Carrot	Marigold	*Centrosema pubescens*
* Chilli pepper	* Ornamental Hibiscus	Cinchona
* Cucumber	* Zinnia	Coffee
* Eggplant	....	* Kenaf
French bean	....	* *Leucaena glauca*
Lettuce	....	* *Mimosa invisa*
* Okra	....	* Papaw
Potato	....	* *Phaseolus calcaratus*
* Pumpkin	....	* *Phaseolus mungo*
* Tomato	....	* *Tephrosia candida*
* Tree Tomato	....	Tea
		Tung (*Aleurites* spp.)

* Recorded hosts.

Most of the above records refer only to the northern part of the Gazelle Peninsula. However, natural infection of *Leucaena* has been recorded at Popondetta and in the Markham Valley. There is strong evidence that a marked decline in vigour results if *Leucaena glauca* is attacked during the first year of growth. However, mature *L. glauca* is affected to a much lesser degree. Among the cover crops, both *Phaseolus mungo* (mungo bean) and *P. calcaratus* are particularly susceptible, but *Crotalaria* spp. seems to be very resistant and *Pueraria phaseoloides* (kudzu) is also resistant.

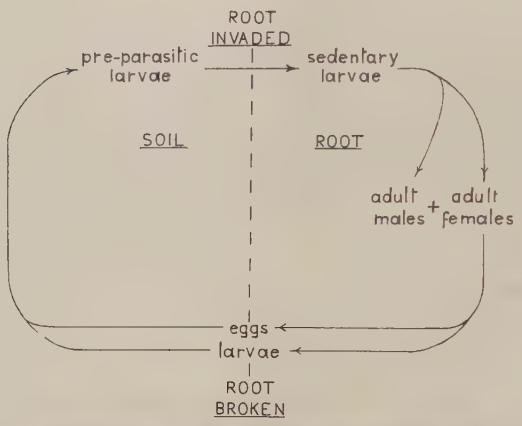
* Mr. L. B. Thrower was Pathologist, Lowlands Agricultural Experiment Station, Keravat, his present address is Department of Botany, University of Melbourne.

Description and life-history

Most plant-parasitic eelworms are less than one millimetre long, and so are practically invisible to the naked eye. Typically, the body is elongate and slender and the mouth has a stylet with which the cells of the host may be punctured. However, the form of the egglaying female of the root-knot nematode differs from that of many other eelworms.

The life-cycle of *Meloidogyne* spp. is illustrated in Fig. I. Eggs hatch in the soil and give rise to the preparasitic larvae (Plates 1 and 2) which move through the soil to the roots of a suitable host. A root is penetrated until the larva reaches a layer close to the conducting tissue. At this stage the male and female worms are indistinguishable, but thereafter their development is quite different. Normally, females greatly outnumber the males and parthenogenesis (development of eggs without fertilization) may occur in densely-parasitized roots.

Fig. I.



The female eelworm injects a substance into the surrounding cells which causes them to swell. From these giant cells the worm absorbs its food. Simultaneously, the female nematode begins to swell until it becomes a pear-shaped object which is just visible to the naked eye (Plate 3). Eggs are produced, usually about 500 per female, and deposited in a mucilaginous substance secreted by the worm. When the root rots, or is broken, these masses of eggs, or the larvae that have developed from them, are liberated into the soil so that a new cycle of infection is begun. The larval nematode is very susceptible to unfavourable conditions, but the egg is an extremely resistant structure.

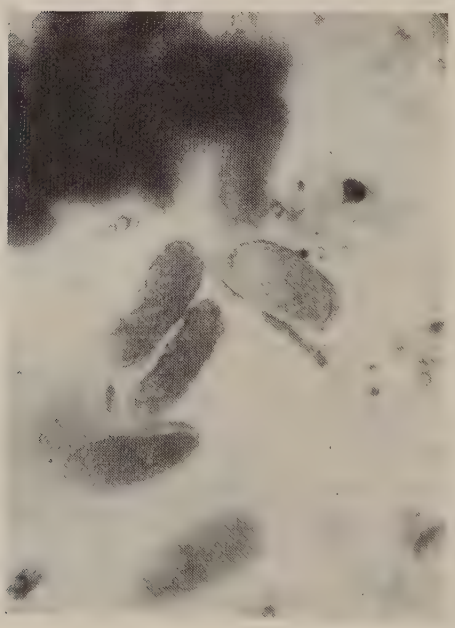


PLATE 1. A group of five nematode eggs.

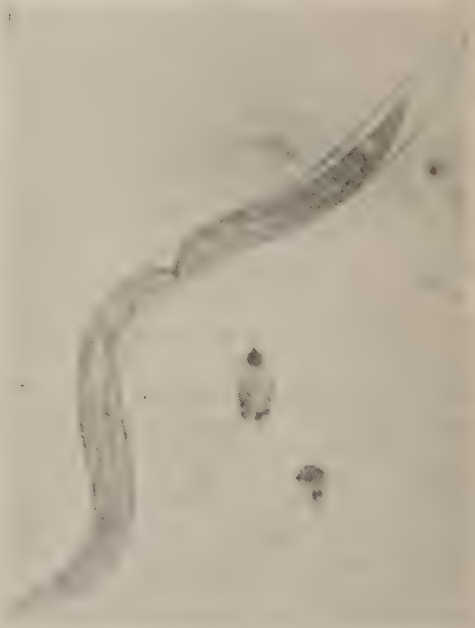


PLATE 2. Larva of root-knot nematode. (x 260)

Recognition

As a result of invasion by root-knot nematodes, galls or "knots" are formed on the roots of susceptible plants (Plates 4 and 5). These galls may vary in size from a small structure to three inches in diameter. Young

PLATE 3. Mature female of root-knot nematode.

plants may be killed outright, although this is a comparatively rare occurrence. In less severe cases, unsatisfactory growth and reduced yields result, due both to removal of food by the parasites and interference with the conducting system of the roots.

Although the formation of knots is the characteristic and most spectacular symptom of attack by this nematode, such structures are not always produced. Instead the surface of the roots may be damaged so that fungi and bacteria may gain entry and rot the tissues.

When a knot is cut across with a sharp knife, the egg-laying females can often be distinguished as minute spots having a different colour from the surrounding tissue ; they can be seen quite clearly with the aid of a hand lens. If the gall is pressed, the females and masses of eggs may be squeezed out from the cut surface.

Root knots and nodules

Some of the leguminous plants that are used as cover crops are susceptible to attack by the root-knot nematode. The peculiar feature of many legumes is that nodules are formed on their roots by a group of bacteria named *Rhizobium*. In this situation, the bacteria are able to "fix" atmospheric nitrogen so that this plant nutrient becomes available to the plant from a source other than the nitrogenous compounds in the soil. The process of nitrogen fixation may thus result in improved growth of the leguminous plant.

Small knots on the roots of leguminous plants may be mistaken for nodules. The appearance of the nodules is illustrated in Plate 6, and this should be compared with the root knots shown in Plates 4 and 5. In addition, some features of root knots and nodules are compared in Table II.

Control

Before discussing the specific measures that may be used to control the root-knot eelworm, some factors that influence the distribution and establishment of the nematode will be considered.

Normally, nematodes travel slowly through the soil, although eggs may be carried by water to regions which were previously free from infestation. Root-knot is often particularly

PLATE 4. Galls formed by the root-knot nematode on the roots of young *Leucaena glauca*. Uninfected roots appear on the left for comparison.

TABLE II.—*Comparison of root knots and nodules.*

—	Root Knots	Nodules.
Size and shape	Less than 1/10th inch to 3 inches in diameter ; irregular shape.	1/10th inch to ¼ inch in diameter, sometimes formed in clusters ; shape fairly regular, spherical or lobed.
Colour	Internally white or cream-coloured with deformed conducting tissue readily visible.	Effective nodules are pink internally ; ineffective nodules are a greenish colour.
Attachment to root	Formed as a swelling which projects from the surface of the root and which may partly or wholly surround it.	Nodule is attached by a short stalk, about 1/16th inch long, to main body of root.

prevalent in soils with a sandy texture or a high content of organic matter.

Some species of plants are much more susceptible to damage by the eelworms than are others ; for example, tomato, eggplant and cucumber are particularly liable to attack but peanuts, sorghum and maize are more resistant.

Introduction of eelworms into clean soil should be avoided. Clean soil may be infested accidentally, for example by using the litter of *Mimosa invisa,* a recorded host of the nematode as a mulch on gardens.

By observing simple precautions it is possible to prevent the population of eelworms from increasing to such an extent that economic cultivation is no longer practicable. After a garden crop, e.g., tomatoes, has finished bearing, the roots should be examined for signs of damage and, if these are found, the ground should be planted to a more resistant crop, such as maize. All infected material should be scrupulously removed and burnt. If susceptible hosts are planted several times in succession on infested soil, the population of nematodes will increase to such a level that only poor crops will be obtained.

Small areas of intensively-cultivated soil

PLATE 5. Heavily infected root system of *Phaseolus mungo.*

PLATE 6. Nodules on the roots of *Phaseolus mungo* (left) and *Leucaena glauca.* Note the more regular shape of the nodules compared with the root-knots, and their more tenuous attachment to the roots.

TABLE III.—Properties of some common soil fumigants

Fumigant	Description.	Hazards.	Cost (Approximate).	Phytotoxicity.	Rate of application.	Delay in planting.	Soil treatment.
Chloropicrin	Yellowish liquid; Corrosive to metals	Reasonable care required; used as a "tear-gas".	2 lb bottles £1 6s.	Phytotoxic	25 gal./acre 1 teaspoonful/ s. ft.	10 days	Compact soil surface immediately after application of fumigant.
D-D mixture	Black liquid; boiling range 95-150°F.	Toxic; reasonable care required.	1 gal. tin £1 10s.; 4 gal. drum £5 11s.	Phytotoxic; not within 3 ft. of living plants.	12-16 gal./acre ½ teaspoonful/s.ft.	3 weeks	Water seal desirable, i.e., soil sprayed with water after injecting fumigant.
Ethylene dibromide	Colourless liquid; non-corrosive	Toxic; reasonable care required to avoid contact and inhalation.	1 gal. £1 2s. 6d. 4 gal. £4 4s.	Phytotoxic; not within 1 ft. of living plants.	20 gal./acre 1 teaspoonful/ s. ft.	10 days	Compact soil surface immediately after application. Water seal advantageous but not essential.
Methyl bromide	Colourless, odourless gas (B.P. 40°F.); non-inflammable	Vapours toxic to man and animals.	1 lb. pressure canister 13s. 9d.; also 125 lb. containers.	Phytotoxic	1 lb./400 s. ft. of soil surface. Expose to gas for 24-36 hours.	48 hours	Soil covered with plastic sheet beneath which gas is applied.
Nemagon	Brown liquid; mildly pungent odour. Boiling point 384°F.; flash point 170°F.	Avoid inhalation or contact with skin.	2 gal. £19 16s. 4 gal. £37 13s. 8d.	Crops vary in tolerance to fumigant.	Tolerant crops 4-8 gal./acre. Intermediate crops less than 2 gal./acre.	Tolerant crops no delay. Intermediate crops allow delay of 8 days per gal. used per acre.	Inject at 6" depth at intervals of 12-15". Do not apply to very wet or dry soil.

* Costs appropriate at time of writing, are approximate only and may vary in different areas.

which have become infested can often be freed from the nematode by some form of sterilization or fumigation. One simple method is to spread the soil thinly on an iron plate beneath which a fire is burning. If this process is properly managed considerable quantities of soil can be treated. The sterilized soil is then returned to the beds and the crop is planted immediately.

Pots or boxes of soil may be treated by pouring boiling water over them in the proportion of seven gallons per cubic foot of soil.

A simple chemical treatment for potting soil or soil in shallow beds is to apply a solution of one part of commercial formalin in one hundred parts of water at the rate of 1½ gallons per square yard of surface soil. The soil should be stirred so that it is thoroughly wetted, and planting should be delayed for seven days after treatment.

A number of other substances have been used successfully as soil fumigants. However, the fact must be pointed out that these chemicals are toxic to plants and can be used only as pre-planting treatments. Furthermore, only the eggs and larvae in the soil can be reached by such fumigants so that all plants and infected debris should be removed before fumigation. Little work has been done on soil nematocides in this Territory and, as yet, their only application would appear to be in vegetable cultivation. The information in Table III is included so that interested persons can become aware of the materials that are available. When soil is to be treated with a fumigant, it should be worked finely and freed from clods, which are not readily penetrated by the vapour.

The foregoing remarks apply particularly to the cultivation of vegetables and ornamental plants. For the planter, the situation is somewhat different. In an earlier section, it was stated that *Leucaena glauca* may be attacked by the root-knot nematode. Few serious cases have been encountered but, in such instances, stakes should be used as planting material if these are available. Among the cover crops, *Phaseolus calcaratus* and *P. mungo* should not be planted where eelworms have been noticed. The resistant *Crotalaria anagyroides, C. goreensis* or *Pueraria phaseoloides* should be used instead.

When short-term crops are considered, a rotation that includes resistant species is important as a control measure. Most of the grasses, including maize and sorghum, possess a high degree of resistance to the eelworm. Peanuts are also resistant to the species of root-knot nematode that have been recorded in Papua and New Guinea to date.

SUSPECTED BOTULISM IN POULTRY

BY T. L. W. ROTHWELL *

BOTULISM has been recorded in most parts of the world in fowls and ducks. A clinical diagnosis of the disease has been made previously in Papua. Outbreaks can usually be traced to the ingestion of spoiled food, decaying vegetable matter, or carcases of dead animals. In the suspected outbreak described in this article a large commercial flock at Lae was involved.

Six thousand birds are kept on the farm where the outbreak occurred. All birds over six weeks of age are run on a modified colony house system. During the day free range into the surrounding bush is allowed the pullets in order to supplement the diet with green feed. It was amongst 1,000 of these pullets that the disease manifested itself. Unfortunately losses had been going on for five days before the owner became fully aware of the seriousness of the situation. It is a standard procedure on the farm for native employees to dispose of fowl carcases as soon as they are found. Over 100 carcases were disposed of in five days before it was reported to the owner that an abnormal number of deaths was occurring.

On the sixth day the author was called in to give advice. Four clinical cases were presented and the following clinical signs were seen. The affected birds were disinclined to move, appearing drowsy, with their eyes dull and partly closed. There was a progressive paralysis of the leg and wing muscles and the gait when the bird was forced to move was unsteady. The head was held in a characteristic fashion with the point of the beak resting on the ground. As paralysis developed the head hung loose and finally a comatose state was reached in which the affected birds died a few hours later. A looseness of the feathers was observed in some birds. Post-mortem signs were generally negative. There was a slight enteritis in one bird and several lesions considered to be those of coryza were present.

The owner was advised to confine the birds to their houses and to search the surrounding area for carcases. Eighteen carcases in various stages of decomposition were found and destroyed.

Losses ceased within a day of the birds being confined and no further losses were suffered when the birds were again released on the ninth day.

In all 150 of the 1,000 pullets were lost—a mortality rate of 15 per cent.

Botulism is caused by the ingestion of the toxin produced by the anaerobic bacterium *Clostridium botulinum*. The bacterium grows in decaying organic matter, when suitable conditions of acidity and temperature are present. As it grows it produces a powerful toxin which is very resistant to extremes of temperatures. Very small amounts of the toxin will kill birds or animals which eat material contaminated with it. Animals dead of botulism constitute a further hazard for other individuals which might happen to eat portions of them. This could conceivably have occurred in the outbreak described.

To confirm a diagnosis of botulism it is necessary to demonstrate the presence of the toxin in the intestinal contents of affected animals. This is done by injecting bacteria free filtrates of the material into experimental animals, some of which have been immunised against botulism. Death in non-protected and survival of immunized animals is used as the criterion diagnosis of the disease. The Lae outbreak was not confirmed in this manner but there is considered to have been sufficient evidence in the clinical signs seen and the disease history to support the diagnosis of botulism.

The outbreak emphasises the need for cleanliness and hygiene in poultry runs and the need for the rapid diagnosis and treatment of any disease which occurs.

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